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Abstract

The eighth inventory of Michigan's forests, completed in 2014, describes more than 20.3 million acres of forest land. The data in this report are based on visits to 4,289 forested plots from 2009 to 2014. Timberland accounts for 95 percent of this forest land, and 62 percent is privately owned. The sugar maple/beech/yellow birch forest type accounts for 19 percent of the State's forest land, followed by aspen (12 percent) and white oak/red oak/hickory (7 percent). Balsam fir, red maple, and sugar maple are the three most common species by number of trees. Growing-stock volume on timberland has continued to increase and now totals about 30.2 billion cubic feet (ft^3).

The associated net growth, harvest removals, and mortality totaled 674, 313, and 303 million ft^3/year, respectively. In addition to information on forest attributes, this report includes data on forest health, land use change, family forest owners, timber-product outputs, and future forests. Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found online at https://doi.org/10.2737/NRS-RB-110.

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Cover: Quaking aspen. Photo by Dave Kenyon, MI DNR, used with permission.

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Foreword

Michigan is a state like no other in the Nation with two peninsulas and a large latitudinal gradient. From the warmer agriculture and urban areas in the south to the colder wooded lands in the north, the State offers unique ecosystems, land uses, and one of the most diverse forests in the United States.

Michigan has more forest land than any other state in the Northeast or Midwest. Nearly all of its forest land was cut and/or burned during European settlement (Dickmann and Leefers 2003). The lumber boom and fires occurred primarily in the late 1800s and early 1900s. By 1920, the lumber boom had ended and secondary succession and recovery of the forests had begun.

Since then, these forests have been maturing and forest management has evolved. Michigan's State Forests and a number of large private ownerships are certified as practicing sustainable forestry through the Forest Stewardship Council (FSC) and the Sustainable Forestry Initiative (SFI). The U.S. National Forests are managed under the National Forest Management Act and the National Environmental Protection Act. There also are assistance programs to help small forest land owners. An active, diverse wood products industry exists which provides jobs and goods to meet consumer demands.

The status and trends of forest resources can indicate how Michigan's forests are fairing over time in the face of physical and social changes. The U.S. Forest Service, through its Forest Inventory and Analysis (FIA) program and in partnership with the Michigan Department of Natural Resources (MIDNR), Forest Resources Division, inventoried the State's forest resources periodically in 1935, 1955, 1966, 1980 and 1993. In 2000, Michigan's periodic inventory was replaced with an annual inventory in which a portion of the field plots are measured each year. The first full sample set of annually collected plots was completed in 2004 and has been annually updated ever since. Using the annual inventory, forest resource reports are created every 5 years with past reports for 2004 and 2009. The current 2014 report covers recent observations from 2009 to 2014 (6,635 plots) and change observations from 2004–2009 to 2009–2014 (6,116 plots).

In this report we describe and highlight the current status and trends observed within Michigan's forests. We invite you to read and consider this report knowing that it will stimulate additional discussion, analysis, and education about one of Michigan's greatest treasures.

Contents

Highlights

Forest Features

- Among the 50 states, Michigan ranks 23rd in area but 12th in forest land area, accounting for 20.3 million acres. Timberland accounts for 95 percent of this forest land or 19.3 million acres.
- Reversion (nonforest to forest) has outpaced diversion (forest to nonforest) since the 1980 inventory and has resulted in the highest estimate of forest land since the 1930s. Since the 2009 inventory, annual reversion has been approximately 3 percent and annual diversion has been approximately 1 percent.
- The southern Lower Peninsula has the least amount of forest land at 18 percent but it is experiencing the most change to forest land, accounting for 72 percent of the State's increase since the 2009 inventory.
- Overall, the forests continue to mature. The number of sawtimber-size trees continues to increase. Shade-tolerant species such as eastern white pine are increasing in number and volume while intolerant and short-lived species such as paper birch are declining.
- There are 14.1 billion trees on forest land, 63 percent of which are hardwoods. The number of sawtimber-size trees on forest land increased 7 percent from 2004 to 2009 inventory and increased 9 percent from 2009 to 2014 inventory. The number of saplings and poletimber-size trees remained steady since 2004.
- There are 34.8 billion cubic feet (ft^3) of live tree volume on forest land or about 1,715 ft^3/acre. Although Michigan is still experiencing an increase in volume, this increase has slowed, partially due to the lower rate of growth that accompanies the maturing of Michigan's forests. From 1955 to 1966 for growing stock on timberland, the increase was nearly 4 percent per year. Since 1980, growing-stock increases have varied from approximately 1.0 to 1.7 percent per year.
- Average annual net growth of trees on forest land was 759.2 million ft^3 or 2.0 percent of current volume on forest land. Since the 2009 inventory, there has been no practical change in total net growth or in the ratio of net growth to current volume at the State level. Every ash species, paper birch, yellow birch, and American beech each experienced negative net growth. The remaining prominent species each experienced a moderate or high ratio of average annual net growth to current volume. Net growth decreased by 17 percent on private ownership in the

southern Lower Peninsula mostly due to an increase in ash mortality. Net growth increased by 50 percent on State and local government ownership in the eastern Upper Peninsula due mostly to gains in live growth by eastern white pine, eastern hemlock, and balsam fir.

- Average annual mortality of trees on forest land was 390.8 million ft^3 which is an increase of 13 percent since the 2009 inventory. The 2014 estimate is 1.1 percent of live volume on forest land, which is low. Since the 2009 inventory, the southern Lower Peninsula was the only region to experience an increase in mortality (65 percent). Disregarding ash, mortality remained stable in the southern Lower Peninsula and dropped 17 percent in the northern Lower Peninsula. With or without ash, there was no notable change in the Upper Peninsula. Considering all species, private ownership experienced an increase in mortality (21 percent). Omitting ash, private (-6 percent) and State and local government (-11 percent) witnessed a drop in mortality.
- Total average annual removals (all removals) of trees from timberland totaled 364.7 million ft^3 for the 2014 inventory. Ninety-seven percent or 352.9 million ft^3 of this total was average annual harvest removals. This harvest estimate is essentially equivalent to the 350.5 million ft^3 of the 2009 inventory. State and local government had a 50 percent increase and private ownership had a 12 percent decrease in harvest removals from the 2009 to 2014 inventory. Variability in the harvest estimates makes it difficult to identify change.
- The net growth to total removals ratio for growing-stock trees on timberland (includes land use change) was 2.1 for both the 2009 and 2014 inventory. This is a moderate to high level and a small drop from historical levels at 2.7. The net growth to harvest removals ratio for trees (growing and nongrowing stock) on timberland (does not include land use change) was 2.0 and 1.8 for the 2014 and 2009 inventory, respectively.

Forest Health Indicators

- Nonnative species such as the emerald ash borer and beech bark disease are playing a larger role in affecting Michigan's forest health. From the 2004 to 2009 inventory, average annual mortality increased nearly seven and more than four times for green ash and white ash, respectively. Since the 2009 inventory, estimates increased approximately five, three, and two times for green, white, and black ash, respectively. For American beech, mortality increased more than five times from the 2004 to 2009 inventory and more than two times since the 2009 inventory.

- The regeneration indicator monitors the abundance of tree seedlings and browse impact over time. Nearly two-thirds of the 345 plots measured since 2012 had at least medium browse impact, an indication that browsing is having an influence on composition of the regeneration component.
- Of the 40 invasive plant species monitored on forest land, 25 were observed on 623 forested plots. Canada thistle was the most commonly observed species (10.4 percent of plots), followed by autumn olive (8.8 percent), multiflora rose (8.7 percent), nonnative bush honeysuckle (8.2 percent), and spotted knapweed (5.5 percent).
- The wildland-urban interface (WUI) is the zone where human development meets or intermingles with undeveloped wildland vegetation. WUI area has been steadily increasing with increasing housing density. In 1990, 17 percent of Michigan's forest land was in low (16 to 128 houses/mile^2) and medium density (129 to 1,920 houses/mile^2) WUI. This increased to 20 percent in 2000 and 22 percent in 2010.

Forest Socioeconomics

- Michigan's wood-products and paper industries directly employ 34,951 workers with an output of approximately $10.2 billion annually. Additional Michigan wood-product jobs and economic outputs are in logging, transportation, trade, and wood furniture industries.
- More than 88 percent of the roundwood harvested in Michigan is processed by Michigan mills. Production and total mill output has remained fairly steady while the number of active mills appears to be in decline since the 1980s.

Background

Managed forest in Iron County, MI. Photo by Dave Kenyon, MI DNR, used with permission.

An Overview of Forest Inventory

What is a tree?

Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. A 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 during this inventory is found in appendix 1. Throughout this report, the size of a tree is expressed in diameter at breast height (d.b.h.), in inches. This is the diameter, outside bark, at a point 4.5 feet above ground.

What is a forest?

FIA defines forest land as land that has at least 10 percent crown cover by live trees or has had at least 10 percent crown cover of live trees in the past and is not currently developed for nonforest use.[1] In general, the minimum area for classification must be at least 1 acre in size and 120 feet in width. There are more specific area criteria for defining forest land near streams, rights-of-way, and shelterbelt strips. Tree-covered areas in agricultural production settings, such as fruit orchards, or tree-covered areas in urban settings, such as city parks, are not considered forest land. The area of forest land sometimes determines the allocation of funding for certain State and Federal programs.

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

FIA defines three types of forest land:

- Timberland—forest land that is producing or is capable of producing crops of industrial wood and is not withdrawn from timber utilization by statute. These areas are capable of producing in excess of 20 ft^3/acre/year of industrial wood in natural stands. Inaccessible and inoperable areas are included.
- Reserved forest land— forest land withdrawn by statutes prohibiting the management of land for the production of wood products (not merely controlling or prohibiting wood-harvesting methods). All private forest land, regardless of conservation easements that may restrict harvesting, is not reserved. Timberland does not include reserved forest land. Examples include state parks, national parks, and federal wilderness areas.

[1] The forest land definition was based on 10 percent stocking prior to FIA field manual 6.0 of the 2013 inventory (O'Connell et al. 2014).

- Other forest land—forest land that is not capable of growing 20 ft^3/acre/year and is not reserved, e.g., some northern white-cedar in low, wet areas or some jack pine on very low-fertility sites. Sometimes such forest lands are referred to as being "less productive" or "unproductive" with respect to wood fiber production.

Timberland accounts for 95 percent of the forest land in Michigan. Nearly 4 percent is reserved and approximately 1 percent is other forest land.

Prior to 2000 in Michigan, FIA measured trees only on timberland plots, so we could not report volumes on all forest land. As a result, trend analyses for tree measurements were limited to timberland. Since 2000, the new annual inventory design allows us to report volumes on all forest land. We have two sets of remeasured plots across all forest land with associated estimates of growth, removals, and mortality.

How do we estimate a tree's volume?

FIA expresses volume in cubic and board feet (International ¼-inch Rule). In Michigan, wood often is measured in cords (a stack of wood 8 feet long by 4 feet wide and 4 feet high). A cord of wood consists of about 79 ft^3 of solid wood and 49 ft^3 of bark and air. When converting from cubic to board feet, there are 4 to 8 board feet per cubic foot because there are losses from cutting rectangular boards from round logs, e.g., squaring the log and saw kerf. Board foot is only applicable for sawtimber-size trees (see Number of Trees).

To estimate volume, FIA used several hundred cut trees with detailed diameter measurements along their lengths (Hahn 1984). Statistical models were applied to this data by species group. Using these models, FIA produces volume estimates for individual trees based on species, diameter, site basal area, and site index. The latter is an expression of the quality of a site to grow specific trees.

FIA reports sawtimber volume in board feet using the International ¼-inch Rule. To convert from the International to the Scribner rule, see Smith (1991).

How much does a tree weigh?

The U.S. Forest Service's Forest Products Laboratory developed estimates of specific gravity for a number of tree species (U.S. Forest Service 1999). These specific gravities are applied to estimates of tree volume to estimate the biomass of merchantable trees (weight of the bole). Regression models are used to estimate the biomass of stumps (Raile 1982), limbs, and bark (Hahn 1984). Currently, FIA does not report the biomass of roots or foliage.

FIA can 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 no moisture content. On average, 1.9 tons (2,000 pounds/ton) of green biomass equals 1 ton of oven-dry biomass.

How do we estimate forest carbon pools?

FIA does not measure the carbon in standing trees, let alone carbon in belowground pools. FIA assumes that half the biomass in standing live and dead trees consists of carbon. The remaining carbon pools (e.g., soil, understory vegetation, belowground biomass) are modeled based on stand and site characteristics (e.g., stand age and forest type). Biomass and carbon are reported in tons (2,000 pounds/ton).

Sample size and error

We measured approximately one plot for every 5,635 acres of land, noncensus water, and inland census water (Great Lakes excluded) in the 2014 inventory. More plots were measured in 2009 (every 2,690 acres of analogous area) and earlier inventories. In 2008, Michigan dropped from a triple- to single-intensity sampling rate for every owner group (sample every 6,000 acres). Triple-intensity sampling resumed on National Forests in 2010 (one sample every 2,000 acres).

Sampling errors are associated with the estimates. The sampling error represents one standard error, which is a 68-percent confidence interval. For instance, the estimate of timberland in Michigan is 19.32 million acres with a sampling error of ±0.7 percent resulting in a range from 19.19 to 19.45 million acres. If the entire population were known, the odds are 2 to 1 (68 percent chance) that the area of timberland would be 19.19 to 19.45 million acres. Error bars shown in some of the figures in this report use one standard error to represent the uncertainty in the estimates. In general, sampling errors for the 2014 inventory will be higher compared to earlier inventories due to the smaller sample size. See "Statistics and Quality Assurance for the Northern Research Station's Forest Inventory and Analysis Program, 2016" (Gormanson et al. 2017; available at https://doi.org/10.2737/NRS-GTR-166) for more information on sampling, sources of error, and determining statistically significant differences between estimates.

Sample interval

In the past, periodic FIA inventories were completed every 10 to 20 years. It took decades with few temporal observations to identify trends. Previous periodic inventories of Michigan's forest resources were completed in 1935, 1955, 1966, 1980, and 1993 (Chase et al. 1970, Findell et al. 1960, U.S. Forest Service 1936, Leatherberry and Spencer 1996, Raile and Smith 1983, Schmidt et al. 1997, Spencer 1983). Areas and volumes were estimated only for total forest land in the 1935 inventory. The 1935 estimates were revised in 1945 to include timberland (U.S. Forest Service 1946). Subsequent inventories have included estimates for forest and timberland.

In 2000, Michigan's periodic inventory was replaced with an annual inventory in which a portion of the field plots are measured each year.[2] The first full sample set of annually collected plots was completed in 2004 and has been subsequently updated each year. Brief resource reports have been created annually along with more comprehensive 5-year reports (Pugh et al. 2009, Pugh et al. 2012). For this 5-year report, estimates for current variables such as area, volume, and biomass are based on 4,289 forested plot samples (total sample of 6,635 plots) collected from 2009 to 2014. Change variables such as net growth, removals, and mortality are based on a total sample of 6,116 plots collected in 2004–2009 and 2009–2014. The annual inventory allows us to identify recent trends such as the ever-increasing mortality of ash. However, it is still necessary to look over long time periods because many trends like succession can be difficult to discern in short time spans.

Analyzing FIA data

Definitions, methods, location, ownership, precision, scale, and temporal trends are important factors to consider when analyzing FIA data. Estimates are derived from sample plots throughout a state. Larger areas of interest will contain more plots and thus produce more reliable estimates. For example, there usually are sufficient plots within several adjacent counties with which to provide reliable estimates for general categories of interest like all forest land. There may not be enough plots associated with specific delineations such as a single forest type. It also is important to consider the degree to which a variable can be measured precisely. For instance, a stand variable like age is not as precise as forest type and a tree variable like crown dieback is not as precise as diameter.

Location and ownership also are important considerations when analyzing the status and trends of forests. Forest resources vary by region and ownership group. For instance, some forest types are more plentiful in specific regions and ownership groups, e.g., northern red oak in the northern Lower Peninsula and red pine on public

[2] One-fifth of the plots were measured annually from 1999 thru 2013 resulting in a complete set of samples for every 5 years of data collection. In 2014, this 5-year cycle was changed to 7 years, wherein 1/7th (14.3 percent) of the plots are measured annually. See Gormanson et al. 2017.

land. In the 2014 inventory, National Forest estimates will tend to have more precision due to triple-intensity sampling on National Forests versus single-intensity sampling on other ownerships.

The southern and northern Lower Peninsula and eastern and western Upper Peninsula are recognized as the four major regions in Michigan with distinct climate, geology, and physiology. FIA has four inventory units in Michigan, the boundaries of which follow county boundaries (Fig. 1). In this report, FIA inventory units are used as boundaries for the four major regions. These units are spatially similar to Albert's (1995) regional landscape ecosystem sections.

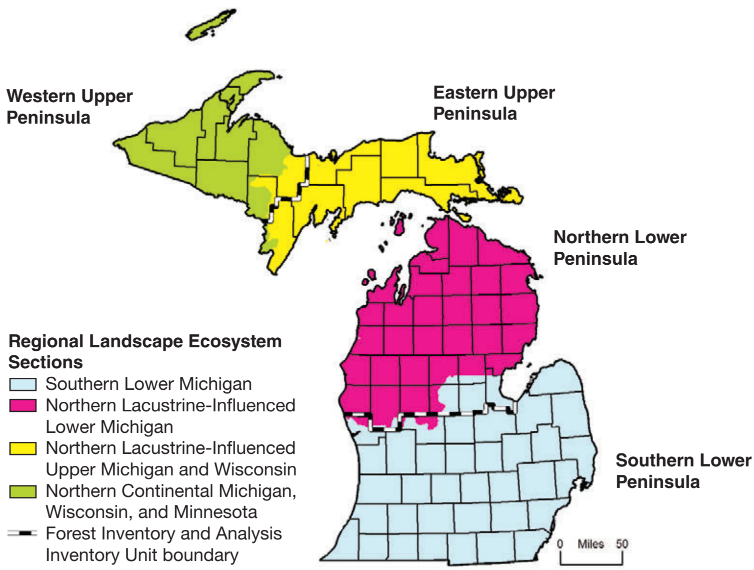

Figure 1.—Regional landscape ecosystem sections and FIA Inventory units or regions, Michigan. For data source and description of this map, see appendix 2.

Besides reviewing definitions and procedural changes, it is often helpful to investigate multiple variables over time to corroborate changes and identify their causes. As an example, when analyzing changes in stand size, one also should look at changes in number of trees by size class. In another example, changes in forest-type acreages should be supported by changes in the associated tree species.

Continually improving FIA inventory

To improve the consistency, efficiency, and reliability of the inventory, updates have been implemented over time. FIA endeavors to be precise in definitions and implementation. The program tries to minimize changes to these definitions and to collection procedures, but that is not always possible or desirable in a world of changing values, objectives, and technology. While change is inevitable, we hope that through clarity and transparency forest inventory data will be of use to analysts for decades to come.

Unlike other inventories, the 1993 inventory included modeled plots, that is, many plots were measured in 1980 and projected forward using the STEMS85 growth model (Belcher et al. 1982, Holdaway and Brand 1986). This was done to save money by reducing the number of undisturbed plots visited in the field. Unfortunately, the use of modeled plots introduced errors, so the practice was discontinued (Pugh et al. 2009).

Major changes occurred with the annual inventory that started in 1999. For the sake of consistency, a new, national plot design was implemented by all five regional FIA units in 1999 (Gormanson et al. 2017). Prior to this new plot design, fixed and variable-radius subplots were used in the 1980 and 1993 inventories. The new design uses fixed-radius subplots exclusively. Both designs have strong points but they often produce different classifications for individual plot characteristics. Unpublished FIA research comparing these plot designs showed no noticeable difference in volume and tree-count estimates. The annual inventory includes observations from all forest land types, whereas observations on reserved and other forest land were limited in periodic inventories.

Methods for determining stocking, forest type, and stand-size estimates were improved twice since the annual inventory started. All annual data were updated with the improvements to facilitate easier temporal analyses. There were fewer and less precise forest types assigned in the periodic inventories. For additional information, see Arner et al. 2003.

Methods for estimating net growth, mortality, and removals were updated after the 2004 inventory. Improvements were made to compensate for changes in site conditions (e.g., site index and basal area) and/or tree class (e.g., growing stock and cull). In addition, an increase in the sample size of ingrowth (trees reaching minimum sample size of 5 inches d.b.h.) improved precision. The new methods had negligible effect on mortality and removals estimates. Pugh et al. 2009 adjusted the net growth estimates for the 2004 inventory to align more with the updated methods. The improved estimates for the 2004 inventory are used in this report to facilitate improved comparisons with the 2009 and 2014 inventories.

Since 2005, we have improved our ability to identify land use and land cover change using updated technology with superior digital aerial imagery, geographic information systems, and global positioning systems (Pugh 2012). We observed a high reversion rate, nearly 5 percent, from 2005 to 2010 and determined that approximately half of this was due to recently identified reversions that occurred in the late 1990s to early 2000s. Using the updated technology, we observed approximately 3 percent of nonforest land reverting to forest from the 2009 to 2014 inventory.

In an effort to increase consistency among states and across inventory years, a refined set of procedures determining reserve status have been implemented with version 6.0 of the FIA field manual which took effect with the 2013 inventory (U.S. Forest Service 2013). Furthermore, all previously collected annual inventory data (1999 to present) have been updated using the new standardized interpretation.

The following are classified as reserved in Michigan using the new implementation:

- State parks, natural, scenic, and recreation areas
- National wilderness, recreation, scenic, and monument areas
- National scenic, recreation, and wild river areas on federal ownership
- National Park Service areas
- U.S. Fish and Wildlife Service areas

Prior to this implementation, wilderness areas on public land, National Park Service land, and State Natural Areas accounted for nearly all reserved forest land identified by FIA.

The 2012 inventory was the last inventory in which all data were available under the previous and improved implementations (Table 1). Small but significant changes are associated with timberland acreage, number of trees, volume, and biomass. The changes associated with the remaining timberland estimates are minor given the inherent variability in the associated estimates.

The improved implementation of the reserve status definition increases the spatial and temporal precision of timberland estimates allowing for higher quality trend analyses and potentially better forest management decisions.

Table 1.—Comparison of timberland estimates calculated using previous and improved reserve status implementations, Michigan 2012. Volumes are for trees 5 inches and larger in diameter.

Timberland	2012 estimate improved	2012 estimate previous	Difference	Difference (percent)
Area (thousand acres)	19,298	19,685	-388	-2
Number of live trees ≥1 inch diameter (million trees)	13,366	13,641	-275	-2
Aboveground biomass of live trees ≥1 inch (thousand oven-dry tons)	809,601	829,103	-19,502	-2.4
Net volume of live trees (million ft^3)	32,305	33,106	-801	-2.4
Net volume of growing-stock trees (million ft^3)	29,748	30,482	-735	-2.4
Annual net growth of growing-stock trees (thousand ft^3/yr)	667,881	677,832	-9,951	-1.5
Annual mortality of growing-stock trees (thousand ft^3/yr)	284,522	293,369	-8,847	-3
Annual harvest removals of growing-stock trees (thousand ft^3/yr)	309,034	309,034	0	0
Annual other removals of growing-stock trees (thousand ft^3/yr)	15,861	13,626	2,235	16.4

A word of caution on harvest suitability and availability

Many factors make timberland unsuitable or unavailable for timber harvesting. For example, operability on some sites is poor (e.g., wet or steep) and there are limitations related to wildlife. Threatened or endangered species habitat, deer yards, and old-growth areas may be subject to harvest restrictions. There may be denied legal access to some locations and the cost of entering some sites is prohibitive. There also are visually sensitive areas where aesthetics outweigh gains from harvests. FIA includes variables such as slope, physiographic class, and disturbance class that could help identify some lands with timber harvest constraints.

It is difficult to determine the availability of wood from private land. Many private land owners do not mention harvesting timber as a reason for owning timberland. In response to the National Woodland Owner Survey (NWOS) conducted by FIA, only 15 percent of private forest land owners (ownerships with at least 10 acres of forest land) holding approximately 2.4 million acres in Michigan stated that they would sell timber within the next 5 years (Butler et al. 2016; see Family Forest Owners). Further, 50 percent of the forest land (ownerships with at least 10 acres of forest land) or approximately 4.1 million acres is owned by people who have never commercially harvested trees.

FIA data can only aid in identifying possible land available for timber production. FIA excludes reserved forest land in the estimate of timberland but the FIA definition of reserved forest land does not account for all forest land that is unsuitable or unavailable for timber harvesting. It would be difficult to identify and maintain an up-to-date list of all lands unsuitable or unavailable for timber harvesting due to changing laws, owner objectives, markets, and site conditions.

Where can I find additional information?

Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found in Gormanson et al. 2017. This site also has most of the data used in this report accessible through EvaliDator (requires Microsoft Access). Some graphs and tables in the printed portion of this report show only a sample of the prominent categories and values available for summarizing data. EvaliDator has more categories, summary values, and custom tables. Definitions of tables and fields are available in the database user manual (O'Connell et al. 2014) available at http://www.fia.fs.fed.us/library/database-documentation/.

The main web page for FIA is at http://www.fia.fs.fed.us/. From here there are resources such as publications (http://www.fia.fs.fed.us/library/) and data and tools (http://www.fia.fs.fed.us/tools-data/). Forest Inventory Data Online (http://apps.fs.fed.us/fia/fido/index.html) and EvaliDator (http://apps.fs.fed.us/Evalidator/evalidator.jsp) are the primary estimation tools. Field guides are at http://www.fia.fs.fed.us/library/field-guides-methods-proc/.

Annual reports for individual states, including Michigan, are available at http://nrs.fs.fed.us/fia/data-tools/state-reports/default.asp. In addition to annual reports, this site has supporting tables and other up-to-date information for each state.

Forest Features

White pine near Munising, MI. Photo by Dana Carothers, U.S. Forest Service.

Forest and Timberland Area

Background

Area estimates are the most basic and standard of all forest inventory attributes. Changes in amount of forest and timberland can be indicative of natural factors or human caused changes in land use, sustainability, and forest health. Summarizing general stand characteristics such as size and age class can provide additional information on the status of the forest resource.

What we found

Fifty-four percent of land in Michigan is forested (20.3 million acres). Timberland accounts for 95 percent of this forest land or 19.3 million acres (Fig. 2). Four percent of the forest land is reserved and 1 percent is other forest land.

Figure 2.—Forest land and timberland by year, Michigan (error bars represent 68 percent confidence interval around estimate; no error bars available for 1935 and 1945).

The Upper Peninsula of Michigan accounts for only 29 percent of the land in Michigan but has 45 percent of the forest land (4.2 and 5.0 million acres for eastern and western Upper Peninsula, respectively). The southern Lower Peninsula has the least amount of forest land (3.6 million acres or 18 percent of forest land) even though it is the largest region. The northern Lower Peninsula has the most forest land, with 7.5 million acres.

Sixty-two percent (12.6 million acres) of Michigan's forest land is owned by families, individuals, private corporations, and other noncorporate private groups (Table 2 and Fig. 3). The latter groups include nongovernmental conservation and natural resource organizations; unincorporated local partnerships, associations, and clubs; and Native American tribes. Families or individuals (45 percent) own the most forest land.

Table 2.—Area and percentage of forest land by owner, Michigan, 2014.

Ownership	2014 estimate	2014 ratio	Change since 2009	Change since 1993
	1,000 acres	*percent*	*percent*	*percent*
Family or individual	9,126.5	45.0	2.1	7.0
State	4,210.0	20.7	0.2	6.7
Corporate	2,813.5	13.9	-3.1	-21.7
U.S. Forest Service	2,738.1	13.5	1.7	1.8
Other federal	302.3	1.5	5.1	20.8
Other nonfederal public	433.3	2.1	20.0	64.3
Other private	673.7	3.3	29.3	4,514.7
Total	20,297.4	100.0	2.0	5.2

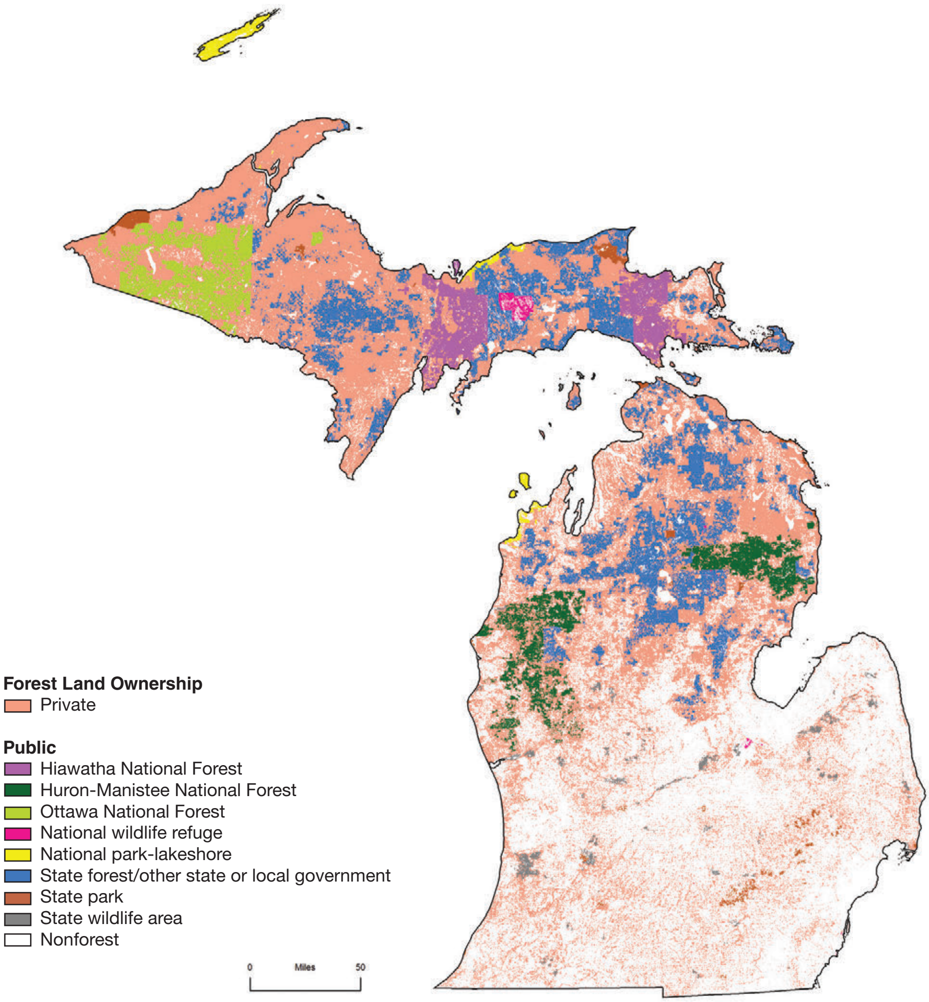

Figure 3.—Forest land ownership, Michigan, circa 2015. For data source and description of this map, see appendix 2.

Corporations are the second largest private forest land owners with 14 percent of forest land. Many large holdings, particularly in the Upper Peninsula, are owned by corporations primarily composed of timber investment management organizations (TIMOs) and real estate investment trusts (REITs). In 2005 and 2006, there were large land transactions involving TIMOs and REITs in Michigan (Froese et al. 2007).

Public forest land (7.7 million acres or 38 percent) is owned by Federal, State, and local government agencies with the State (21 percent) and U.S. Forest Service (13 percent) being the primary owners. Depending on the specific tract of land, these forests may be managed for wildlife habitat, water protection, nature preservation, timber production, recreation, other uses, or, quite commonly, a combination thereof. Public forest land has been increasing gradually. Between 1993 and 2009, the area of public forest land increased just over 5 percent, due mostly to an increase in State lands. Between 2009 and 2014, the area of public forest land increased nearly 2 percent with a noticeable increase in local government ownership (20 percent or 72,000 acres).

Ownership patterns vary across the State (Fig. 3). The eastern and western portions of the Upper Peninsula and the northern Lower Peninsula have relativity high concentrations of public ownership (50, 40, and 42 percent, respectively) compared to the more fragmented forests of the southern Lower Peninsula (14 percent). These differences affect not only the forest resources and their management practices but also recreation opportunities and other benefits for the public.

Since the first FIA inventory in 1935, timberland has been a fairly constant proportion of all forest land (ranging from 95 to 98 percent). The greatest estimates of forest and timberland were observed in the 1955, 2009, and 2014 inventories (Fig. 2). The least amount of forest land was identified in the 1980 inventory and the least amounts of timberland were noted in the 1945 update of the 1935 inventory (U.S. Forest Service 1946) and in the 1980 inventory. Changes in forest land are depicted in Figure 4, which shows the percentage of forest land by county and changes in forest land by region. In 1945, over 1 million acres of forest land was classified as other forest land or chiefly valuable for other than forestry purposes, disqualifying the land as timberland. Currently, less than one-quarter of a million acres is other forest land. The large amount of forest land in 1955 was the result of the forest base recovering from the land clearing, timber harvests, and fires in the 1800s and early 1900s. There was a substantial gain in cropland from 1966 to 1980 and as a result, a decrease in forest land. During the 1980s and early 1990s, the area of forest and timberland increased. Abandoned cropland and pasture reverted to forest, and marginal forest lands, once classified as less productive, were reclassified as productive timberland (Schmidt et al. 1997).

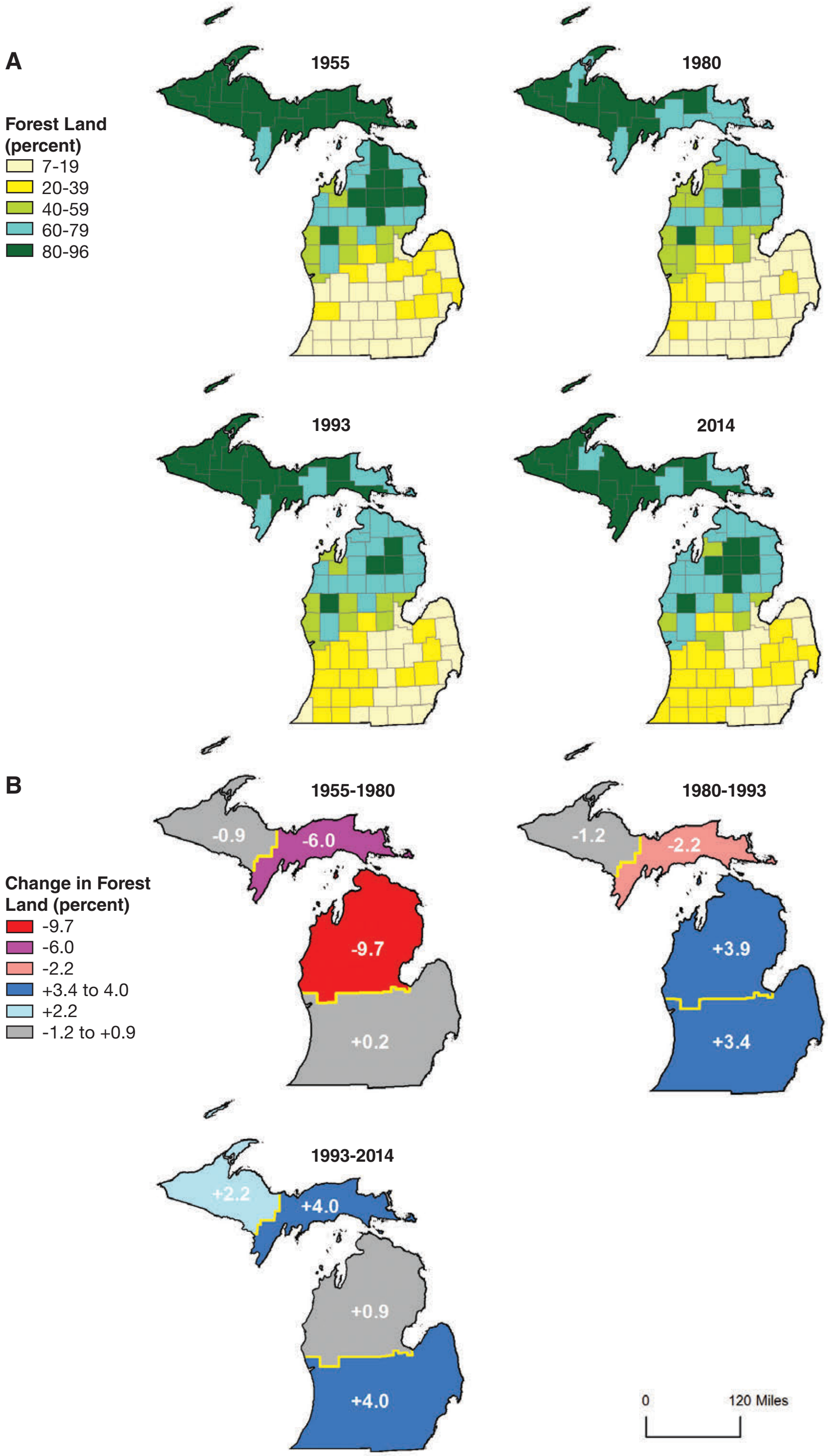

Figure 4.—Percentage of forest land by county (A) and change in forest land by region (B), Michigan, 1955-2014. For data source and description of this map, see appendix 2.

From 1993 to 2004, there were no substantial changes in the estimates of total forest or timberland but there were reversions and diversions. Land change from nonforest to forest typically is referred to as reversion and land change from forest to nonforest typically is referred to as diversion. From 1993 to 2004, 2 percent of forest diverted to nonforest and 3 percent of nonforest reverted to forest (Pugh et al. 2009). Between 2004 and 2009, reversion was nearly 5 percent and diversion was between 1 and 2 percent.

The actual reversion rates for the 2004 and 2009 inventories differ from the previously mentioned estimates. FIA initially identifies forest and nonforest land categories from interpreting aerial imagery. All plots currently identified as forest from imagery are inventoried on the ground and any previously forested plots are also visited on the ground. Plots that do not appear to be currently forested and were not previously forested are not visited on the ground. Technology used in the 2004 inventory (e.g., aerial imagery) was not as high of quality as that used in the 2009 inventory. Pugh (2012) determined that approximately half of the reversion rate for the 2010 inventory was due to recently identified reversions that occurred in the late 1990s to early 2000s. Hence, the previously reported reversion rate was high for the 2009 inventory and low for the 2004 inventory.

Since 2005, we have improved our ability to identify land use and land cover change using updated technology with superior digital aerial imagery, geographic information systems, and global positioning systems. Using updated technology, we observed reversion (512,000 acres) and diversion (266,000 acres) at 3 and 1 percent, respectively, from 2009 to 2014.

Reversion has outpaced diversion since the 1980 inventory resulting in the current estimate of 20.3 million acres of total forest land. Since 1980, most reversion has been happening in the southern Lower Peninsula followed by the northern Lower Peninsula and most has been associated with private ownership. Between 2009 and 2014, estimates of forest land increased by 2.0 and 8.5 percent for the northern Lower and southern Lower Peninsula, respectively. The southern Lower Peninsula has the least amount of forest land at 18 percent but it is experiencing the most change to forest land, accounting for 72 percent of the State's increase.

Reversions and diversions come from a variety of sources (Fig. 5). In the 2014 inventory, most diversion occurred in the Lower Peninsula where farmland, developed/cultural, and water/marsh/wetland accounted for 46, 18, and 17 percent, respectively. Diversion in the Upper Peninsula is dominated by water/marsh/wetland (50 percent), rights-of-way (25 percent), and developed/cultural (16 percent). Most reversion in the southern (58 percent) and northern (44 percent) Lower Peninsula was from farm and pasture/rangeland combined. Development was the source for approximately 25 percent of reversion in the Lower Peninsula. In the Upper Peninsula, water/marsh/wetland was the source for nearly 50 percent of reversion followed by farmland at 28 percent.

Michigan's forests have been maturing, as can be seen in the distribution of timberland by stand-size classes (Fig. 6). Stand-size classes represent the size of the trees that form the plurality of stocking based on the dominant trees sampled. Since the 1935 inventory, acreage has been increasing in large diameter stands (plurality of sawtimber-size trees). Acreage in small diameter stands (plurality of seedlings/saplings) was declining until the 2009 inventory.

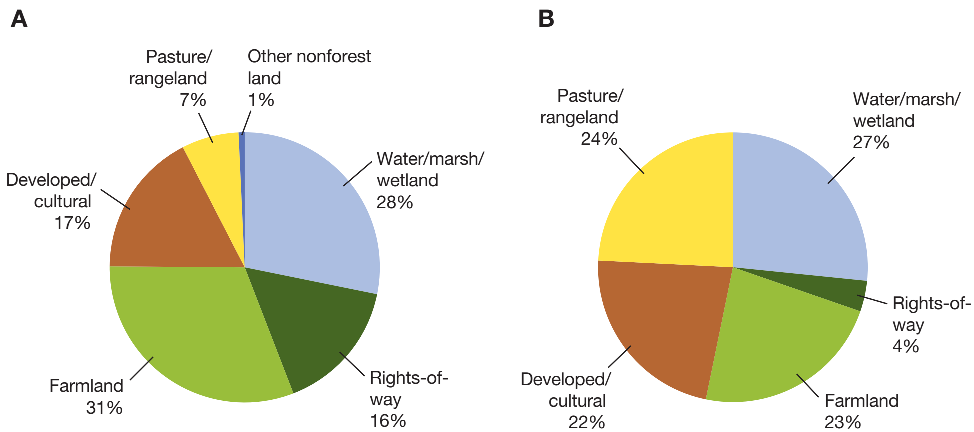

Figure 5.—Percentage of forest land diversion by current land use (A) and forest land reversion by previous land use (B), Michigan, 2014.

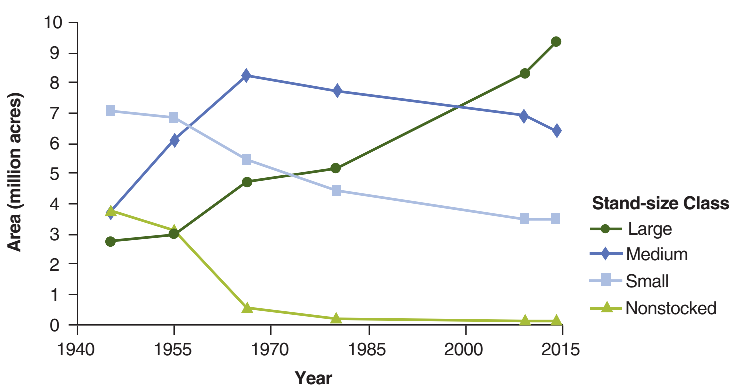

Figure 6.—Area of timberland by stand-size class and year, Michigan.

It is important to look at changes in number of trees by size class in conjunction with changes in stand-size class since methods for determining stand-size class are less precise and have changed over time. By contrast, methods for determining tree size class are more precise and have not changed. Since 1980, the number of sawtimber-size trees increased by 77 percent. The number of saplings increased by 15 percent and the number of poletimber-size trees increased by 3 percent. From 2009 to 2014, the number of sawtimber-size trees increased 10 percent while the numbers of sapling and poletimber-size trees appeared steady.

The current stand-age class distribution in Michigan indicates that most stands are 40 to 80 years old and that 22 percent of timberland area is younger (Fig. 7). Five percent of timberland area is over 100 years old. Since the 2009 inventory, it appears that acreage increased in stands from 60 to 100 years old and decreased in stands from 20 to 60 years old. Estimates of stand age are less precise than most other stand variables. One reason for this is that the estimate of stand age is based on the composition of all age classes within a stand. Often, stands are heterogeneous by age, but FIA methods require a single value be assigned.

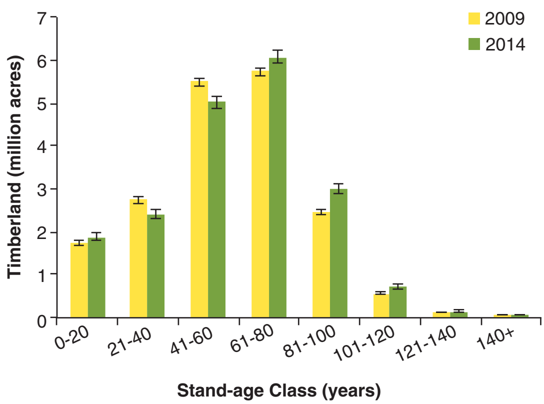

Figure 7.—Area of timberland by stand-age class, Michigan, 2009 and 2014.

There are nearly 1.4 million acres of timberland designated as plantations in the 2014 inventory. Eighty-four percent of this artificially regenerated acreage is in softwood types with red pine comprising 50 percent. Jack pine ranks second at 14 percent. In plantations, 69 percent of red pine acreage is less than 60 years of age and 73 percent of jack pine acreage is less than 45 years of age. However, 50 percent of naturally regenerated jack pine acreage, twice the plantation area at 424,000 acres, is more than 45 years of age. Jack pine stands more than 45 years old are more vulnerable to pests.

What this means

Michigan's forest land base has remained relatively stable at the State level. Ninety-nine percent of forest land in 2009 remained so in 2014, but the land remains in flux. At the State level, estimates of forest land have been increasing since the 1980 inventory. Losses in forest land may occur as development or other diversions increase but the current forest land estimate is at the highest level since the 1930s.

Current forest stand-size and age-class distributions indicate a maturing forest resource but there are young stands with 22 percent of timberland identified as less than 40 years old. Forest management and land use changes can greatly affect the distribution of stand-age classes. The overall trend toward maturing forests is expected to continue.

Forest Type Distribution

Background

Forest type is determined by the stocking (relative density) that tree species contribute to a sample condition (see Stocking and appendix 3). In stands with a mixture of size classes, the assignment of forest types is heavily weighted toward the larger trees, which contribute more to stocking. The current distribution comes from many influences ranging from competition between species, succession, and natural and manmade disturbances. The modeled distribution of forest-type groups in Michigan, based on FIA plot attributes and ancillary data (e.g., information on topography and climate), is shown in Figure 8. Related forest types are combined into forest-type groups that can then be used with other information, such as soils and climate, to create regional ecosystem classifications. Here, we focus primarily on specific forest types. Forest types are named based on a single or few species but the types are often comprised of many species (Gormanson et al. 2017). For example, overall, the jack pine forest type is 63 percent jack pine, 22 percent red pine, 3 percent white pine, 2 percent red maple, and 10 percent other species by volume (live trees at least 5 inches d.b.h.).

Figure 8.—Distribution of forest-type groups, Michigan, 2010. For data source and description of this map, see appendix 2.

What we found

Michigan has a diverse set of forest types. Most forest land is categorized as a hardwood forest type (73 percent) followed by softwood (24 percent), mixed (3 percent, comprised of softwood species such as jack or red pines and hardwood species such as oak or aspen), and nonstocked (1 percent). Forest types comprising at least 2 percent of forest land account for 83 percent of the acreage (Figs. 9, 10, 11). The distribution of forest types on timberland matches the forest land distribution in Figure 9.

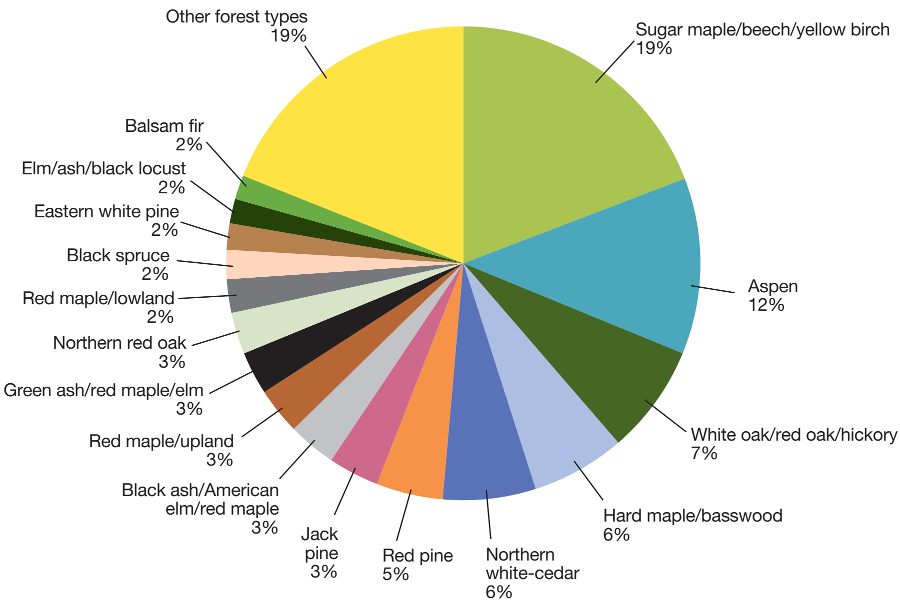

Figure 9.—Percentage of forest land by forest type, Michigan, 2014 (types that comprise at least 2 percent of forest land acreage).

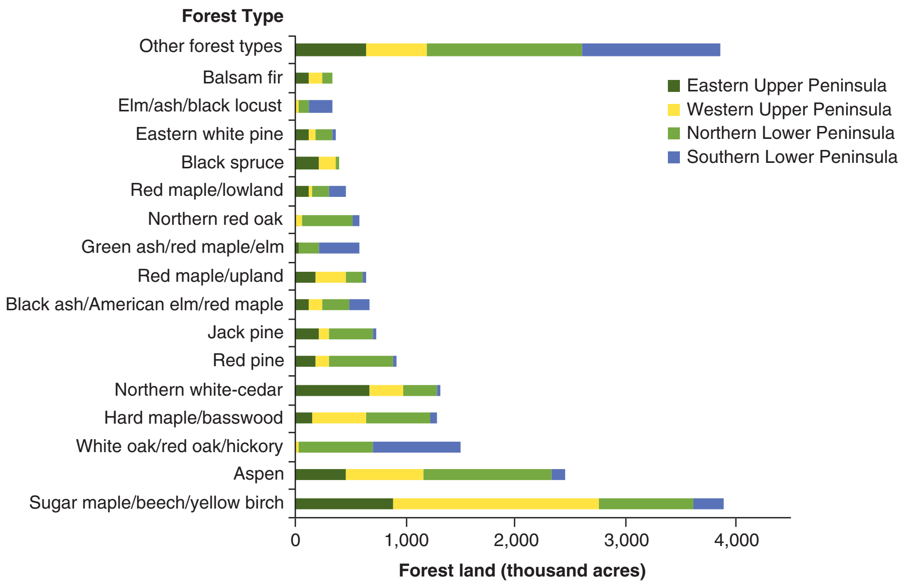

Figure 10.—Area of forest land by forest type and region, Michigan, 2014 (types that comprise at least 2 percent of forest land acreage).

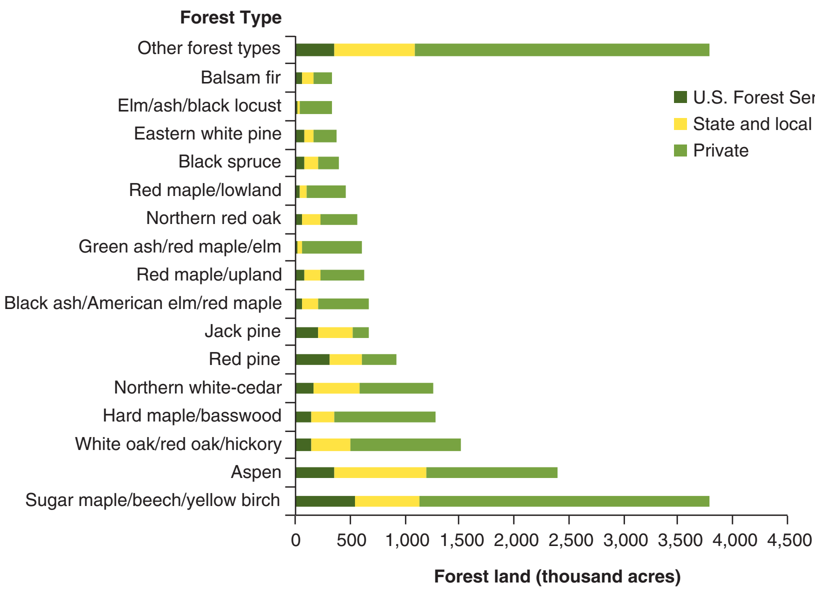

Figure 11.—Area of forest land by forest type and ownership group, Michigan, 2014 (types that comprise at least 2 percent of forest land acreage).

No single forest type comprises more than 19 percent of forest land (Figs. 9, 10, 11). Sugar maple/beech/yellow birch is the predominant forest type in Michigan. Every region and ownership group has at least some of this forest type. Sixty-eight percent is privately owned and the largest portion (48 percent) is in the western Upper Peninsula. Aspen is the second most abundant forest type with 49 percent privately owned and 48 percent occurring in the northern Lower Peninsula. Northern white-cedar is the most abundant softwood forest type; 54 percent is privately owned and 53 percent is in the eastern Upper Peninsula.

Forest-type distributions vary by region (Fig 10). Black spruce (52 percent) and balsam fir (34 percent) are relatively abundant in the eastern Upper Peninsula. The northern Lower Peninsula has most of the northern red oak (79 percent), red pine (64 percent), and jack pine (53 percent). The southern Lower Peninsula has relatively little acreage in many of the prominent types, however, this region has the bulk of the white oak/red oak/hickory (53 percent), green ash/red maple/elm (66 percent), and elm/ash/black locust (66 percent) forest types.

Some forest types are relatively more abundant in certain ownership groups given the amount of forest land in each group (Fig. 11). For example, jack pine (76 percent publicly owned) and red pine (66 percent publicly owned) are relatively more abundant on public land. Balsam fir (35 percent), aspen (32 percent), northern white-cedar (32 percent), and black spruce (30 percent) are more common on State and local government land. Sugar maple/beech/yellow birch (68 percent), sugar maple/basswood (72 percent), black ash/American elm/red maple (69 percent), green ash/red maple/elm (89 percent), red maple/upland (77 percent), and elm/ash/black locust (91 percent) are found most often on private land. Some forest types such as green ash/red maple/elm, elm/ash/black locust, and white oak/red oak/hickory are low in acreage on U.S. Forest Service land. These forest types are primarily in the southern Lower Peninsula where the U.S. Forest Service owns virtually no forest land.

Over the decades there have been many changes in the area of forest types. The definitions have changed among past inventories but are constant from 2000 to present. From 2004 to 2014 acreage increased in the sugar maple/beech/yellow birch (7 percent), white oak/red oak/hickory (17 percent), red maple/upland (21 percent), green ash/red maple/elm (43 percent), red maple/lowland (57 percent), and white pine (38 percent) types. Acreage in black ash/American elm/red maple decreased (17 percent). From 2009 to 2014 acreage decreased in the aspen (8 percent) and black spruce (17 percent) types but increased in sugar maple/beech/yellow birch (7 percent) and red maple/lowland (25 percent) types.

Area increases by forest type have coincided with increases in the number of trees by species (see Number of Trees and appendix 4). For example, pole and sawtimber-size red maple have been increasing in number and are major contributors to red maple/upland, red maple/lowland, green ash/red maple/elm and sugar maple/beech/yellow birch forest types. Sugar maple, black oak, and eastern white pine are other species increasing in number and contributing to acreage increases for previously mentioned forest types. The population of green ash had been rising for decades and contributing to the expansion of associated forest types but the increase stopped in the 2014 inventory.

What this means

Site characteristics, past utilization, and adaptive abilities of species within forest types have influenced the distribution of forest types in Michigan. As land was cleared and logged during the European settlement, early successional species and associated forest types such as aspen and paper birch became established. These forest types have peaked and declined in acreage. Many of these early successional species depend on fire to regenerate, but wildfire has been suppressed. Some aspen and paper birch forest types have converted to late successional forest types, primarily to sugar maple/beech/yellow birch. Within the sugar maple/beech/yellow birch and aspen forest types, sugar maple, red maple, and aspen are the most abundant species by volume and are among the most important species to the State's wood-products industry (see Timber Product Output) and wildlife.

There are many other examples of forest-type acreage changing over time. There has been gradual increases in softwood forest types such as northern white-cedar since the first inventory in 1935. The increase in these forest types is partly due to succession, operability constraints (too wet), and wildlife concerns. Another example is the result of planting programs by public agencies in the last century. Thousands of acres of softwoods were planted; red pine was the most popular plantation species 50 to 80 years ago. The red pine forest type has increased with the planting and maturing of these red pine trees. These planting programs are also partially responsible for the relative abundance of jack pine and other pine/hardwood forest types on public land.

We recently observed a decrease in acreage for black ash/American elm/red maple. At this time, there is no obvious link between the mortality of ash and changes in acreage among forest types. Much of the decrease in black ash/American elm/red maple is from conversions to other forest types within the same forest-type group, e.g., elm/ash/cottonwood. Ash is a common species within the forest-type group and changes among forest types within the group are normal.

Forest types are adapted to occupy specific sites or ecological niches and each region is unique. These niches vary the greatest between the southern Lower Peninsula and the rest of the State. The transition between the southern and northern Lower Peninsula is the southern range of many northern tree species, (e.g., northern white-cedar, jack pine, and black spruce), and the northern range for many southern tree species, (e.g., black oak and hickory). Climate, soils, physiography, and land use change quite appreciably between these two regions. Consequently, there is a stark contrast in forest type distributions between the southern Lower Peninsula and the rest of Michigan.

There also are many examples where a forest type is preferentially adapted to particular niches and appears more often in these areas. For example, most of the acreage in softwood forest types such as northern white-cedar, black spruce, and balsam fir is in the eastern Upper Peninsula. The species in these forest types are adapted to the relatively low and wet soils of this region. By contrast, most of the acreage in softwood and mixed-forest types, such as jack pine, red pine, and other pine/hardwood, is in the northern Lower Peninsula. The species in these forest types are adapted to the relatively high and dry soils in this region.

Number of Trees

Background

The estimated number of trees in a forest is useful when combined with data on diameter-class distribution. Young forests generally have more trees per acre than older forests but the latter usually have more biomass. The number of trees by size and species defines stocking density, which is an indicator associated with characteristics such as wildlife habitat and timber value. Looking at current numbers and changes over time can identify management issues.

What we found

In Michigan, there are 14.1 and 13.4 billion live trees (at least 1 inch d.b.h.) on forest land and timberland, respectively, or about 695 trees/acre on forest land. Sixty-three percent of the trees on forest land are hardwoods. Softwoods and hardwoods generally follow the same size-class distribution at the State level. Seventy-five percent of these trees are saplings (1 to less than 5 inches d.b.h.), 18 percent are poletimber-size trees (5 to less than 9 inches for softwoods and 5 to less than 11 inches for hardwoods), and 7 percent are sawtimber-size trees. The numbers of trees are fairly well distributed among species with no species accounting for more than 14 percent of trees.

Some species disproportionately occur in certain size classes (Figs. 12 and 13). Balsam fir has more saplings (17 percent of saplings) than any other species in Michigan but accounts for only 2 percent of sawtimber-size trees. Red maple (13 percent) and sugar maple (9 percent) rank second and third in numbers of saplings, respectively.

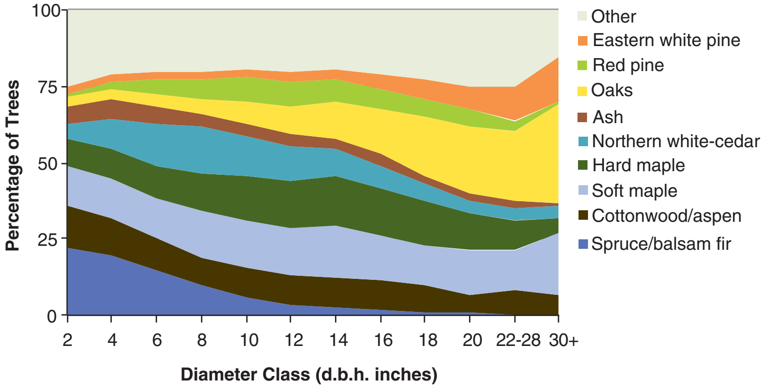

Figure 12.—Proportional species composition on forest land by diameter class, Michigan, 2014. Value shown on x axis represents the midpoint of the 2 inch diameter class, i.e., 6 inches refers to trees with diameters of 5 to 6.9 inches.

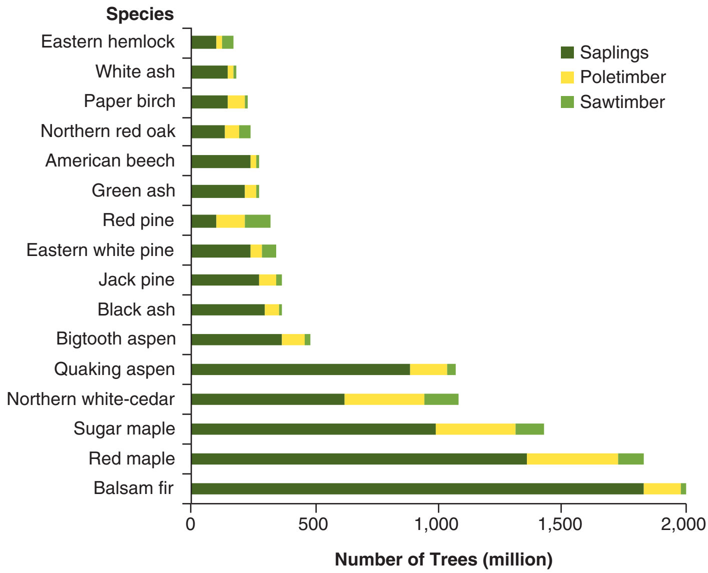

Figure 13.—Number of live trees on forest land by size class and selected species, Michigan, 2014.

Red maple (15 percent), sugar maple (13 percent), northern white-cedar (13 percent), quaking aspen (6 percent), balsam fir (6 percent), and red pine (5 percent) comprise nearly 60 percent of poletimber-size trees. Northern white-cedar (14 percent), sugar maple (12 percent), red maple (11 percent), red pine (11 percent), eastern white pine (5 percent), eastern hemlock (5 percent), and northern red oak (5 percent) account for over 60 percent of sawtimber-size trees. The oaks account for 21 percent of all trees greater than the 18-inch size class but only 3 percent of saplings. Red pine is the only species with more poletimber-size trees than saplings (Fig. 13).

The number of trees on timberland increased from 1980 to 2014 (675 to 694 trees/acre). There was a 24 percent increase in the number of softwoods and a 9 percent increase in hardwoods. Since 1980, the number of sawtimber-size trees increased by 77 percent. The number of saplings increased by 15 percent and the number of poletimber-size trees decreased by 3 percent. Softwoods experienced the largest increase in saplings (24 percent) and sawtimber-size trees (91 percent). The number of hardwood poletimber-size trees decreased by 5 percent and remained steady in softwoods. National Forests have experienced the most noticeable changes in the number of poletimber- (14 percent decrease) and sawtimber-size (107 percent increase) trees. State and local government lands experienced the largest increase in saplings (43 percent).

Most species have experienced substantial changes in the number of trees by size class since the 1980 inventory (Table 3). Red maple, black cherry, eastern white pine, green ash, white spruce, and northern pin oak experienced increases in all size classes. Red maple had the second largest increase in total number of trees at 387 million. Balsam fir had the largest overall increase but this was due to the increase in saplings. Balsam fir had fewer poletimber- and sawtimber-size trees.

Table 3.—Change in number of live trees on timberland by size class and species, Michigan, 1980-2014 (selected prominent species)

	Sapling		Poletimber-size		Sawtimber-size		Total	
	Trees	Percent	Trees	Percent	Trees	Percent	Trees	Percent
	million		*million*		*million*		*million*	
Balsam fir	731	75	-19	-11	-5	-22	707	61
Red maple	262	25	66	22	58	142	387	28
Sugar maple	-526	-36	0	0	56	102	-470	-26
Quaking aspen	65	8	-68	-32	-4	-11	-7	-1
Northern white-cedar	-179	-23	25	9	61	92	-93	-8
Bigtooth aspen	96	36	-13	-12	5	26	89	23
Black cherry	102	52	21	44	15	234	138	55
Black ash	-33	-10	3	7	0	1	-29	-8
Black spruce	-38	-13	-3	-4	4	71	-38	-10
Eastern white pine	126	130	32	144	26	129	183	132
Jack pine	16	8	-58	-48	-5	-24	-47	-13
Red pine	-84	-48	-1	-1	77	350	-8	-2
Green ash	117	126	37	276	10	694	164	153
American beech	115	113	-2	-6	1	6	114	84
Northern red oak	-10	-7	-38	-44	11	37	-37	-14
White spruce	80	103	12	37	5	33	97	78
Paper birch	-58	-30	-71	-55	-2	-16	-131	-39
White ash	10	8	-13	-38	2	21	-1	0
Eastern hemlock	27	39	1	3	10	34	38	30
Yellow birch	-48	-39	-13	-26	-3	-18	-64	-34
White oak	-20	-22	-9	-20	7	51	-23	-15
American basswood	-17	-23	-28	-44	7	50	-38	-25
Black oak	31	116	1	3	13	198	45	81
Northern pin oak	49	747	12	370	8	620	70	621
Silver maple	6	23	9	77	10	279	24	61
Total	821	11	-118	-5	367	76	1,071	10

Sugar maple, northern white-cedar, black spruce, red pine, northern red oak, white ash, white oak, and American basswood are either losing or maintaining sapling and/or poletimber-size trees while gaining sawtimber-size trees. Quaking aspen has decreased in the number of poletimber- and sawtimber-size trees. Bigtooth aspen has also decreased in poletimber-size trees but increased in saplings and sawtimber-size trees. Yellow birch and paper birch lost in all size classes. Jack pine lost in pole and sawtimber sizes.

The number of sawtimber-size trees on forest land increased 7 percent from 2004 to 2009 while the numbers of sapling and poletimber-size trees remained steady. Red maple increased by 4 and 18 percent in pole- and sawtimber-size trees, respectively. Green ash increased by 15 percent in each of pole- and sawtimber-size trees. Red pine (15 percent), sugar maple (7 percent), and black oak (21 percent) made gains in sawtimber-size trees. Black cherry (9 percent) and eastern white pine (11 percent) each increased in poletimber-size trees and white spruce (23 percent) increased in saplings. Black ash saplings decreased (-12 percent) and paper birch (-10 percent) lost in the sawtimber-size class.

Again, the number of sawtimber-size trees increased from the 2009 to 2014 inventory (9 percent). Several species experienced change in numbers from 2009 to 2014 (Table 4). Red maple, silver maple, and black cherry increased in pole- and sawtimber-size trees. Eastern white pine, northern white-cedar, eastern hemlock, and sugar maple increased in the sawtimber-size class. Balsam fir experienced an increase in poletimber-size trees. Black ash lost in saplings and poletimber-size trees. Paper birch lost in poletimber-size trees and black spruce lost in saplings. Eastern hemlock and American beech made gains in saplings.

The number of trees by size class varies somewhat by region or ownership group (Table 5). The numbers of sapling and poletimber-size trees per acre decrease in rank order from the eastern Upper, western Upper, northern Lower, and southern Lower Peninsula, respectively. The number of sawtimber-size trees per acre is lowest in the southern Lower Peninsula. The sawtimber-size trees in the southern Lower Peninsula are slightly larger and there are proportionally more than in other regions (9 percent versus 6 to 7 percent in other regions). This explains the larger estimates for biomass and volume per acre for the southern Lower Peninsula compared to the rest of Michigan (see Volume). National Forests have more pole- and sawtimber-size trees per acre than other ownerships. State and local government ownership has the most saplings per acre.

Table 4.—Change in number of live trees on forest land by size class and species, Michigan, 2009-2014 (includes species with notable change in numbers)

Species	Size class	Change	
		Trees	Percent
		million	
Red maple	sawtimber	15	18
	poletimber	18	5
Northern white-cedar	sawtimber	15	12
Sugar maple	sawtimber	12	12
Eastern white pine	sawtimber	7	16
Black cherry	sawtimber	6	38
	poletimber	10	16
Eastern hemlock	sawtimber	6	15
	sapling	21	27
Silver maple	sawtimber	3	28
	poletimber	5	34
American beech	sapling	45	23
Balsam fir	poletimber	14	9
Black spruce	sapling	-49	-16
Paper birch	poletimber	-8	-10
Black ash	poletimber	-11	-16
	sapling	-56	-16

Table 5.—Number of live trees per acre on timberland by size class and region or ownership, Michigan, 2014

	Sapling	Poletimber-size	Sawtimber-size
	------------------------	*trees/acre*	------------------------
Region:			
Eastern Upper Peninsula	684	150	49
Western Upper Peninsula	571	133	47
Northern Lower Peninsula	493	125	48
Southern Lower Peninsula	331	93	41
Ownership:			
National Forests	520	144	61
State and local government	604	129	42
Private	493	122	45

What this means

With succession as a major influence, some shade-tolerant species are increasing and several intolerant species are declining in number. Although overall numbers for the shade species are on the rise, some, such as sugar maple and northern white-cedar, are losing recruitment or regeneration (young trees). Partial cutting of northern white-cedar stands is recommended for promoting regeneration (Boulfroy et al. 2012) but northern white-cedar has a low harvest removals to current volume ratio (0.37 percent) and there are concerns of over browsing regeneration by deer (Cook 2008; see Regeneration Status). Deer can also negatively impact sugar maple regeneration in some areas. In contrast to northern white-cedar, sugar maple is the most abundant species in the seedling size class (see Regeneration Status) and management often successfully promotes regeneration.

Red pine experienced the largest absolute increase in the number of sawtimber-size trees and also large increases in volume (see Volume). These increases have contributed to the increase in acreage of the red pine forest type. Sawtimber-size trees are weighted more heavily than smaller trees when classifying forest types. Red pine was the most popular plantation species 50 to 80 years ago and now much has grown to a commercially harvestable size. The rate of planting has been low over the past 50 years. Most red pine are poletimber-size trees.

Balsam fir has more saplings than any other species in Michigan and thus balsam fir acreage could increase in the future as saplings mature. Some of this potential increase will be offset by the fact that balsam fir also has decreased in volume (see Volume) and has one of the highest ratios of average annual mortality to current volume (see Annual Mortality). Since 2004, numbers of sapling and sawtimber-size balsam fir have held steady. Balsam fir experienced a possible increase in poletimber-size trees from 2009 to 2014 but acreage in the balsam fir forest type has not increased. The native spruce budworm is a major pest of balsam fir. The last major outbreak of this pest concluded in the early 1980s. But the recent rise in area damaged by spruce budworm indicates the next major outbreak has started (see Insects, Disease, and Decline). Over time, the annual inventory will make it possible to identify emerging trends linked to balsam fir.

The rise in red maple numbers is not isolated to Michigan. It is the most common tree in the United States. Red maple is shade tolerant but it can grow in full sunlight, is found on wet and dry sites, is a prolific seeder, and responds well to disturbance. It is a prominent member of many forest types.

Yellow birch, a midtolerant species, has had health and management challenges for decades. Yellow birch grows primarily in canopy gaps of the sugar maple/beech/yellow birch forest type. Since 2004, the number of yellow birch appears to have stabilized but without aggressive forest management promoting canopy gaps, yellow birch probably will continue its decline.

Paper birch and jack pine are intolerant and dependent on fire to regenerate but wildfire has been suppressed. These species are threatened by various elements (see Insects, Disease, and Decline) and are more susceptible partly because Michigan is located at the southern edge of their distribution. Paper birch will continue to decline, but active management can maintain the jack pine resource. The number of jack pine was dropping but appears steady at this time possibly due to management for wildlife species such as the Kirtland's warbler (*Dendroica kirtlandii*). Pugh (2011) found that net growth was higher and mortality lower for jack pine in areas managed for Kirtland's warbler habitat.

Ash is succumbing to emerald ash borer (EAB). The number of green ash has risen dramatically since 1980 but there was no substantial increase from the 2009 to 2014 inventory. Since 1980, most of the increase in green ash on timberland occurred in the Lower Peninsula on private land (79 percent). Currently, 94 percent of live green ash trees on forest land occur in the Lower Peninsula. The number of black ash has been declining since 2004. Ash has other health threats but the relative change is stark and mostly accredited to EAB. The ratio of recently dead to live black ash trees is 0.87 and 0.32 in the southern and northern Lower Peninsula, respectively. Seventy-five percent of the decrease in black ash trees is on private land in the Lower Peninsula. Currently, the Lower Peninsula has 38 percent of the live black ash trees on forest land. EAB is expected to spread and increase throughout Michigan and recent increases in ash mortality foreshadow further decreases in the number of ash (see Annual Mortality and Insects, Disease, and Decline).

Spruce decline and spruce budworm are two major damaging agents of black spruce. Black spruce usually grows in hydric (very wet) sites but can be found on a variety of soil types. It is susceptible to extended drought and high water. The 80 percent decrease in black spruce saplings since 2009 occurred primarily on hydric soils. Black spruce is generally shallow rooted in the soil and substantial water table fluctuations since 2009 could have contributed to the decrease.

The increase in northern red oak sawtimber-size trees is typical for most of the other oak species. It appears that the acreage of oak forest types has been increasing with the increase in sawtimber-size trees. Only a few oaks, such as northern pin oak and black oak, appear to be gaining in saplings. Most oaks are midtolerant and respond well after fire. Oaks also have a number of health threats. These elements pose management challenges and make it unclear what direction oak acreage will go in the future.

Stocking

Background

The number of trees, sizes, spacing, and species define stocking. Stocking is an expression of stand density expressed relative to a standard. The growth potential of a stand is considered to be reached when it is fully stocked. A standard for some fully stocked medium diameter stands (plurality of poletimber-size trees) is a basal area of 80 ft^2/acre or more. Using this example, a fully stocked small diameter stand, with a basal area less than 80 ft^2/acre, would have a sufficient number of trees to attain a basal area of 80 ft^2/acre when the trees reach poletimber size. For additional information on stocking, see Arner et al. 2003. As mentioned previously, stocking can identify potential management opportunities. For example, trees in overstocked stands may lack adequate light and nutrients to maintain vigor and meet their growth potential. A management activity such as thinning could improve growth and vigor. Methods for determining stocking class changed during the switch to annual inventories, but data available since 2000 use a consistent approach. Temporal comparisons back to periodic inventories are difficult to interpret except that nonstocked acreage dropped considerably after the 1955 inventory and has continued to remain low.

What we found

Seventy-seven percent of Michigan's forest land is medium or fully stocked. Six percent is overstocked and 17 percent is poorly stocked or nonstocked. Stocking levels have not changed appreciably since the 2009 inventory. Wisconsin (34 percent) and Minnesota (36 percent) have less acreage in fully stocked stands compared to Michigan (41 percent).

In Michigan, stocking varies by owner, region, and forest type (Figs. 14, 15, 16). Forest Service lands have the greatest percentage of fully and overstocked stands at 51 and 7 percent, respectively. Private lands have the lowest percentage of fully and overstocked stands at 39 and 5 percent, respectively. State and local government ownerships have 41 and 9 percent fully and overstocked stands, respectively. The Forest Service has a lower percentage of poorly and nonstocked stands (8 percent) compared to private (19 percent) and State and local government (16 percent). These poor and nonstocked areas do not include nonforest land such as barrens, marshes, and rangeland.

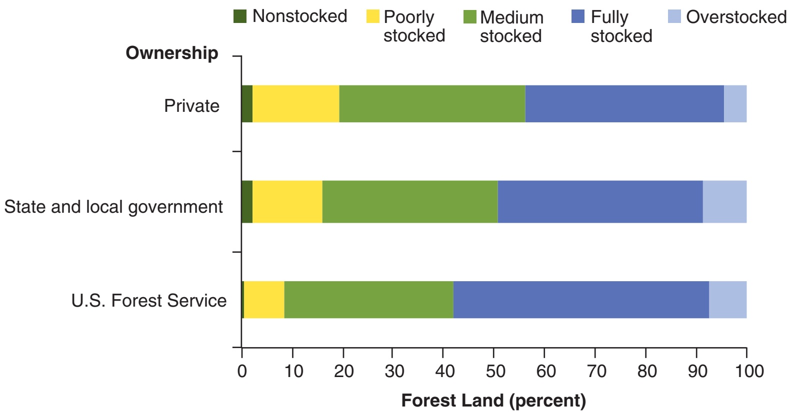

Figure 14.—Percentage of forest land by stocking class and ownership group, Michigan, 2014.

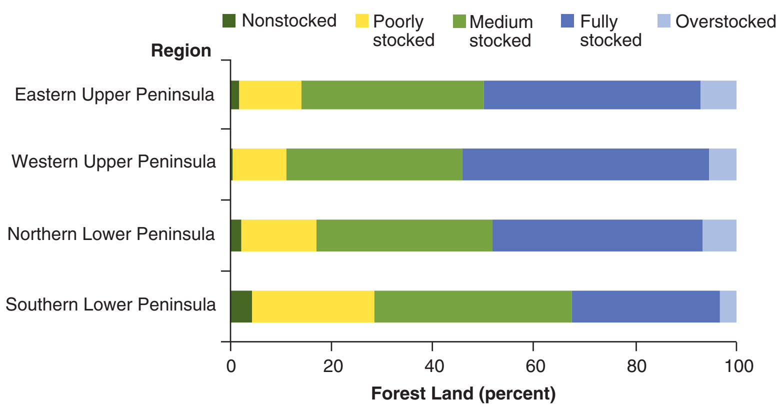

Figure 15.—Percentage of forest land by stocking class and region, Michigan, 2014.

The eastern Upper Peninsula and northern Lower Peninsula have stocking distributions that closely follow the statewide trend (Fig. 15). By contrast, the southern Lower Peninsula has a lower percentage of its stands in the fully (29 percent) and overstocked classes (3 percent) and a higher percentage in the remaining stocking classes (39 percent medium and 29 percent poorly or nonstocked). The western Upper Peninsula has the greatest percentage of fully stocked stands (49 percent) and the lowest percentage of poorly and nonstocked stands at 10 and less than 1 percent, respectively.

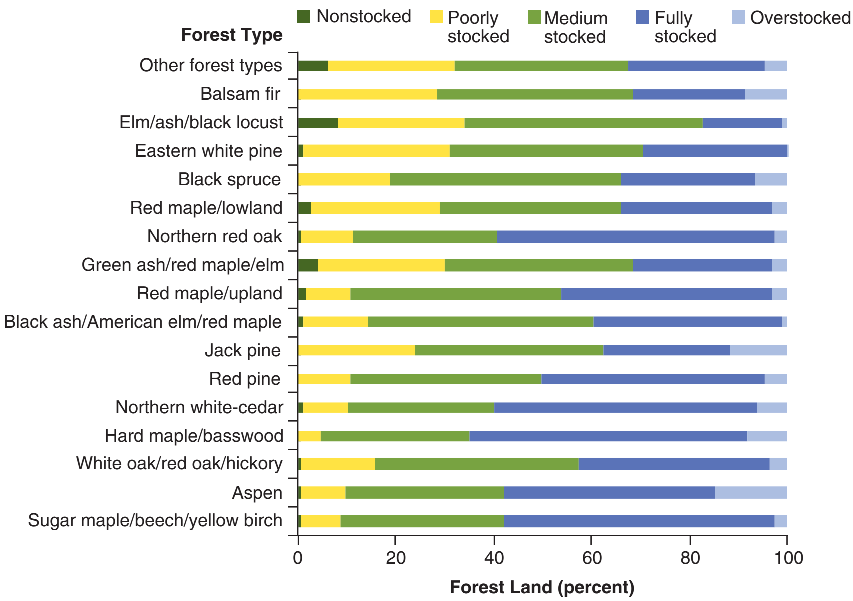

Figure 16.—Percentage of forest land by stocking class and forest type, Michigan, 2014 (types that comprise at least 2 percent of forest land acreage).

Stocking levels vary by forest type (Fig. 16). This variation is influenced by the inherent characteristics of the forest types, site characteristics, and past utilization of the forest types. Hard maple/basswood, sugar maple/ beech/yellow birch, northern white-cedar, and northern red oak forest types have higher percentages of fully stocked stands. Jack pine, green ash/red maple/elm, red maple/lowland, black spruce, eastern white pine, elm/ash/ black locust, and balsam fir forest types have lower percentages of fully-stocked stands and higher percentages of poorly and nonstocked stands. Forest types with the highest stocking (e.g., sugar maple/beech/yellow birch) are more common on mesic sites.

Forest types often associated with nonstocked and poorly stocked stands often occur on hydric or xeric sites. Jack pine is often poorly stocked and found primarily on xeric sites. Black spruce, balsam fir, green ash/red maple/elm, and red maple/lowland forest types often occur on hydric sites. These types have relatively lower stocking levels. Northern white-cedar is an exception with many medium to overstocked stands on hydric sites. The occurrence of these medium to overstocked stands is partly due to the historical development of these stands and limited utilization affected by operability constraints and wildlife concerns.

What this means

The high percentage of fully and medium stocked lands in Michigan is conducive to maintaining forest health, quality timber products, and efficient timber production. Nonstocked and poorly stocked stands are expected with forest types common to relatively wet and dry sites. The southern Lower Peninsula of Michigan tends to have lower stocking but much better soils and site productivity. Forty-seven percent of forest land in the southern Lower Peninsula has a site productivity of at least 85 ft^3/acre/year. The next most productive area is the northern Lower Peninsula, where 26 percent of forest land has a site productivity of at least 85 ft^3/acre/year.

A number of factors contribute to the lower stocking in the southern Lower Peninsula. Some is due to nonforest land reverting to forest land. Fifty-one percent of reversions are poorly stocked and nonstocked forest land. Nearly 60 percent of this reverting nonforest land was cropland and pasture. Twenty-three percent of the reversions came from developed lands. Most of the lower stocking is due to the forest types specific to the region, and activities such as grazing and high-grading, which are common in the region. For example, forest types dominated by trees at risk (e.g., ash and elm) are mostly found in the southern Lower Peninsula (Fig. 10).

Pugh et al. (2012) reported that 55 percent of poorly stocked and nonstocked forest land in 2009 was nonforest in 2004 for the southern Lower Peninsula. A correction has been applied to this estimate. Twenty percent of poorly stocked and nonstocked forest land in 2009 was nonforest in 2004. For the 2014 inventory, 11 percent of poorly stocked and nonstocked forest land was nonforest in 2009 for the southern Lower Peninsula.

The western Upper Peninsula has a higher percentage of fully-stocked stands. The high proportion of U.S. Forest Service and State and local government land contributes to the high stocking in the region. This region also has higher stocking levels than the rest of the State regardless of ownership group. Predominate forest types in the region, such as sugar maple/beech/yellow birch, aspen, and hard maple/basswood, tend to have higher stocking levels.

Volume

Background

Like stocking, current volumes and change in volume over time characterize the forests and reveal important resource trends. It is also useful to compare components of change such as net growth, removals, and mortality, to current volumes. When possible, we focus on live tree volume on forest land; otherwise, growing-stock volume on timberland is presented.

Estimates of live tree volume include live, rough, rotten, and noncommercial species at least 5 inches d.b.h. Growing-stock volume includes trees at least 5 inches d.b.h. and excludes rough, rotten, and dead trees in addition to noncommercial tree species, e.g., eastern hophornbeam and apple.

What we found

There are about 30.2 billion ft^3 of growing stock on timberland (1,566 ft^3/acre) and about 34.8 billion ft^3 of live tree volume on forest land (1,715 ft^3/acre). Of the live tree volume on forest land, 69 and 31 percent are in hardwood and softwood species, respectively. Sugar maple (21 percent), red maple (20 percent), northern red oak (7 percent), quaking aspen (7 percent), bigtooth aspen (5 percent), black cherry (5 percent), and American basswood (4 percent) account for 69 percent of hardwood live tree volume. Northern white-cedar (26 percent), red pine (22 percent), eastern white pine (16 percent), eastern hemlock (10 percent), and balsam fir (6 percent) account for 81 percent of softwood live tree volume. Sixty-two percent of live tree volume is in private ownership. Twenty percent is owned by State and local governments and 18 percent is in Federal ownership (16 percent by U.S. Forest Service). The proportion of softwoods is higher on public land. Thirty-eight percent of forest land is publicly owned; however, public land has 49 percent of the softwood live-tree volume due partially to public planting programs and softwood management since the 1920s. Also, much of the public land is inherently in softwood forest types.

Growing-stock volume on timberland has increased in each inventory since 1955 (Figs. 17, 18). This increase has slowed over time. From 1955 to 1966, the increase was nearly 4 percent per year. From 1966 to 1980, the increase was just over 2 percent per year. Since 1980, growing stock increases have varied from approximately 1.0 to 1.7 percent per year with a nearly steady rate in hardwoods from about 1.2 to 1.5 percent per year. Softwood increases since 1980 have been approximately 2 percent per year, except between the 2004 and 2009 inventories when the rate was approximately 0.6 percent per year.

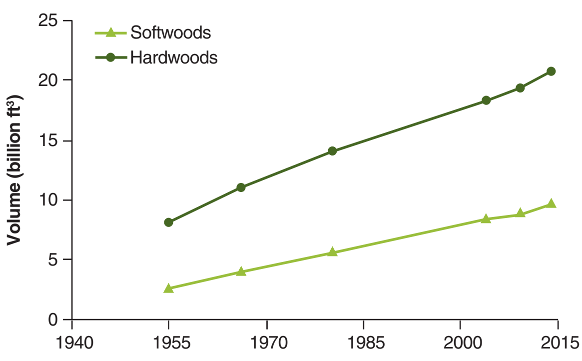

Figure 17.—Distribution of growing-stock volume on timberland by species category, Michigan.

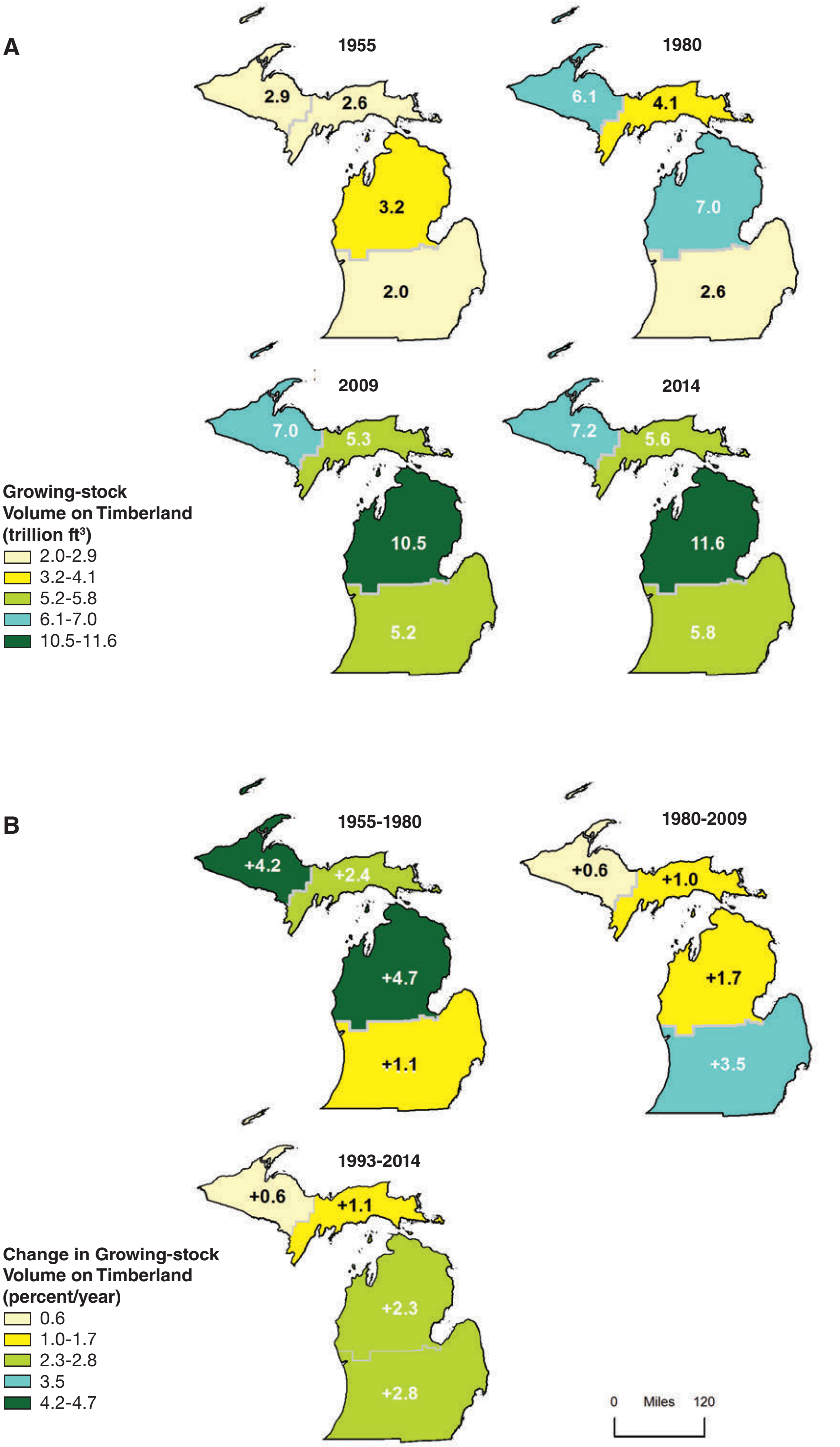

Figure 18.—Growing-stock volume (A) and change in growing-stock volume (B) on timberland by region, Michigan, 1955 to 2014. For data source and description of this map, see appendix 2.

Another way to measure net change uses estimates of growth, removals, and mortality (growth minus mortality and removals). Net change in softwood volume derived using the alternative method was more than double (1.4 percent per year) the estimate derived from comparing volumes in the 2004 and 2009 inventories. Both methods produced the same estimate of 1.2 percent for net change in hardwoods. Comparing volumes in 2009 and 2014, hardwoods and softwoods increased at 1.1 and 1.7 percent per year, respectively. Using the alternative method, the rates were 1.5 and 2.0 percent per year for hardwoods and softwoods, respectively. The growth, removals, and mortality estimates are derived from remeasured plots. Different sets of FIA plots were used for current (e.g., volume) and remeasured estimates.

Just over 8 percent of live tree volume on forest land is in live cull trees, some of which are used in commercial production. Salvable dead trees contribute 1.7 billion ft^3 of volume. These dead trees are important for wildlife and are often used for firewood.

Per-acre basal area by species varies geographically (Fig. 19). There are higher concentrations of softwood basal area in the eastern Upper Peninsula and northeastern Lower Peninsula. The distribution of basal area for the five most common species by volume varies considerably except for red maple, which is found throughout most of Michigan.

Most of Michigan's tree species have experienced significant increases in growing-stock volume since 1980 (Fig. 20). Red pine, black oak, and silver maple have tripled in volume. Eastern white pine and black cherry at least doubled in volume. Green ash has increased more than any other species on a percentage basis since 1980, but there were only 81 million ft^3 of it in 1980. Corresponding with gains in volume, red maple, eastern white pine, black cherry, green ash, white spruce and northern pin oak have increased in number in all size classes (Table 3).

Paper birch, balsam poplar, jack pine, American elm, balsam fir, yellow birch, and quaking aspen experienced losses while white ash, American beech, American basswood, black ash, and black spruce remained relatively constant. Although balsam fir has dropped in growing-stock volume, it has gained over these same years in sapling-size trees (Table 3). The opposite is true for paper birch and yellow birch, which have dropped in number for all size classes. Jack pine has lost in the number of poletimber- and sawtimber-size trees.

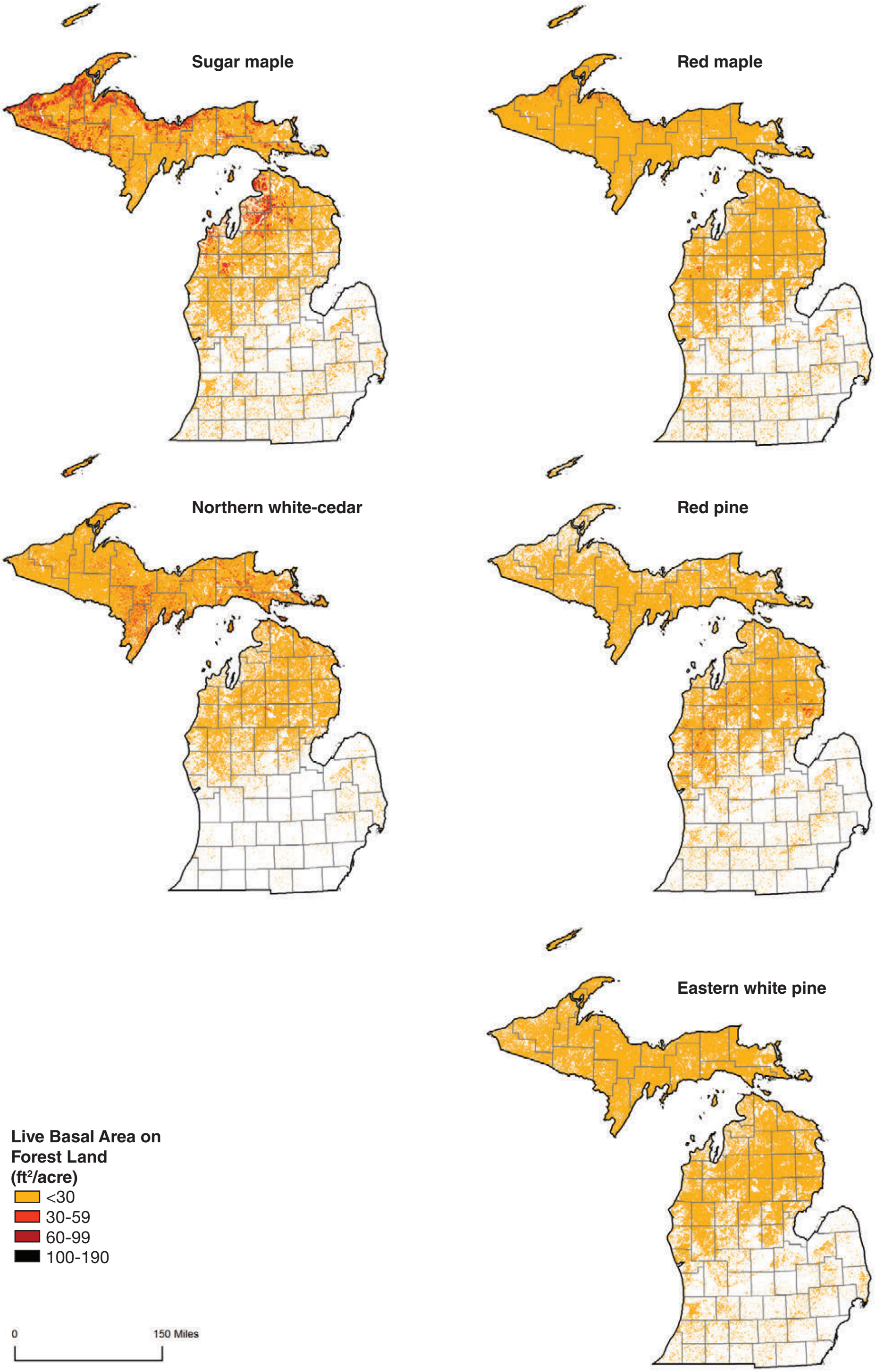

Figure 19.—Basal area of live trees per acre (trees at least 5 inches d.b.h.) on forest land for the five most voluminous species, Michigan, 2010. For data source and description of this map, see appendix 2.

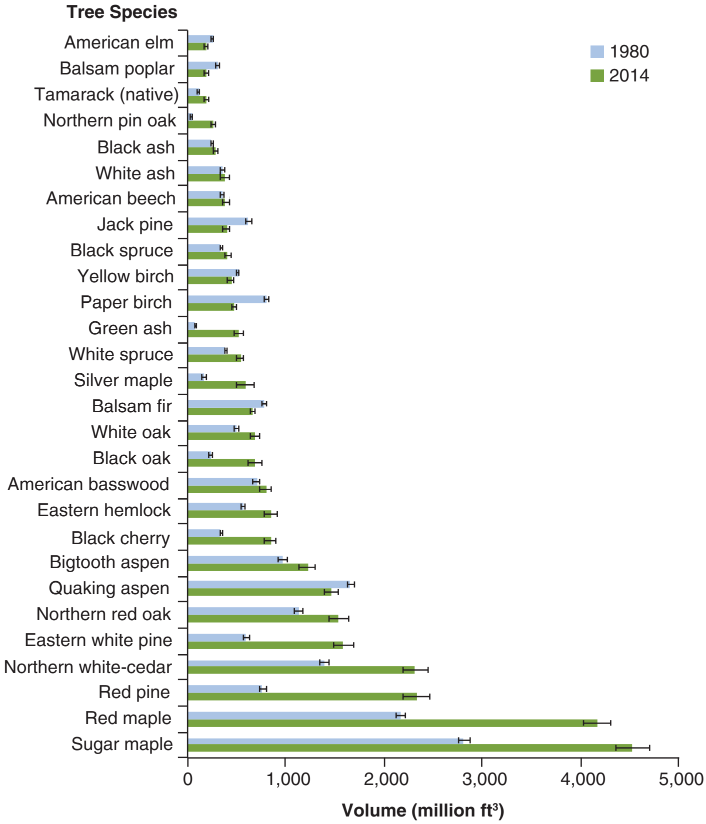

Figure 20.—Growing-stock volume on timberland for selected species, Michigan, 1980 and 2014. Error bars represent 68 percent confidence interval around estimate.

From 2004 to 2014, live tree volume on forest land increased for black cherry (47 percent), black oak (46 percent), eastern white pine (35 percent), silver maple (35 percent), red maple (30 percent), white oak (26 percent), northern pin oak (22 percent), red pine (21 percent), eastern hemlock (19 percent), white spruce (19 percent), northern red oak (15 percent), northern white cedar (12 percent), and sugar maple (11 percent). Black ash (17 percent), jack pine (14 percent), and paper birch (14 percent) decreased.

Total live tree volume and per-acre live tree volume on forest land varies by ownership group and region. Forest Service land has the most per-acre live tree volume (2,047 ft^3/acre) followed by private (1,713 ft^3/acre and State and local government ownership (1,511 ft^3/acre). Since 2004, the Forest Service has seen the largest gain in live tree volume per acre (11-percent increase). Private ownership increased by nearly 10 percent and State and local government ownership increased by just over 8 percent.

The southern Lower Peninsula (1,877 ft^3/acre) has the highest live tree per-acre estimate. The eastern Upper Peninsula has the lowest estimate at 1,552 ft^3/acre. The northern Lower Peninsula (1,698 ft^3/acre) and western Upper Peninsula (1,758 ft^3/acre) each rank midway. Since 2004, the greatest increase was in the northern Lower Peninsula (15 percent) followed by the southern Lower Peninsula (9 percent) and eastern Upper Peninsula (7 percent). The estimate changed minimally for the western Upper Peninsula (3 percent).

What this means

Increases in forest land area and the number of trees, particularly sawtimber-size trees, have led to increases in volume. The U.S. Forest Service has the greatest proportion of fully stocked stands (Fig. 14) and the southern Lower Peninsula has the highest proportion of sawtimber-size trees (see Number of Trees).

Although Michigan is still experiencing an increase in volume, this increase has slowed, partially due to the lower rate of growth that accompanies the maturing of Michigan's forests. Also, invasive pests such as EAB are impacting volume. Black ash volume has recently decreased and the gains in white and green ash have stopped at the State level. The greatest effect is evident in the southern Lower Peninsula where ash volume appears to have peaked in the 2009 inventory at 612 million ft^3 and dropped to 419 million ft^3 (32 percent decrease) in the 2014 inventory.

Estimates of net change have varied by sample (current versus remeasurement) and components (current volumes versus growth minus mortality and removals) employed. Each method has shown steady increases in softwood and hardwood volumes with more variability in the softwood estimate. The variability between methods is not unexpected and appears reasonable.

Sawtimber Volume and Quality

Background

Sawtimber volume is an indicator of value for the trees in Michigan. To qualify as sawtimber, softwoods must be at least 9 inches d.b.h. and hardwoods must be at least 11 inches d.b.h. Sawtimber volume is estimated for the saw-log portion of growing-stock trees measured in board feet (International ¼–inch Rule). Softwood sawtimber is valued primarily for dimensional lumber while hardwood sawtimber usually is valued for flooring, kitchen cabinets, and furniture. Here, our main interest is with live sawtimber volume on timberland.

Tree grade is based on tree diameter and the presence (or absence) of defects such as knots, decay, and bole curvature. The value of sawtimber varies greatly by species and tree grade. Trees are graded 1 through 5 with quality inversely related to grade number. Trees not meeting grade 5 requirements are considered cull. Cull trees are not components of sawtimber volume estimates in this report. Cull trees can be sawtimber size but they are not sawtimber trees. Grades 1 through 4 are assigned to trees that contain a 12 feet grading section in the butt 16 feet of the tree. Grade 5 is assigned to a growing-stock tree that has at least one merchantable 12-foot upper log (above the butt 16 feet of the tree) or two merchantable noncontiguous 8-foot logs. All species of hardwoods are graded 1 through 5 but grades defined for softwoods vary by species. Eastern white pine is graded 1 through 5 but grade 4 is not applied to other pines. Other softwoods, including spruce, fir, hemlock, native tamarack, and cedar, are assigned grades 1 or 5 only. The grading system has changed a number of times. It changed between the 1993 and 2004 inventories and again in 2007. Notable changes in 2007 affected softwood grading (e.g., added grade 5 for all softwoods) while hardwood grading rules have been fairly consistent since 2000. This report's analysis of softwood grades is based only on data from 2009 onward using the most recent grading rules.

What we found

There are 101.7 billion board feet of sawtimber on forest land in Michigan. About 6 percent of the sawtimber volume is on reserved forest land or less productive forest land. There are 95.6 billion board feet of sawtimber on timberland. Of this, 64 percent is in hardwood species. Sugar maple (21 percent), red maple (18 percent), northern red oak (10 percent), bigtooth aspen (7 percent), quaking aspen (6 percent), black oak (5 percent), American basswood (4 percent), and black cherry (4 percent) account for 73 percent of hardwood sawtimber volume. Red pine (28 percent), eastern white pine (22 percent), northern white-cedar (21 percent), eastern hemlock (12 percent), and white spruce (6 percent) account for 89 percent of softwood sawtimber volume. Considering only timberland, 65 percent of sawtimber occurs on private ownership. Nineteen percent is owned by State and local governments and the remainder is in Federal ownership.

Sawtimber volume on timberland has increased in each inventory since 1955 (Fig. 21). From 1955 to 1966, the increase was nearly 4 percent per year. From 1966 to 1980, the increase was just over 2 percent per year. From 1980 to 2004, softwoods increased by nearly 4 percent per year and hardwoods increased by just less than 3 percent per year. Between the 2004 and 2009 inventories, sawtimber volumes for softwoods and hardwoods increased by just over 1 and 2 percent per year, respectively. Since the 2009 inventory, sawtimber volumes have increased by approximately 3 percent per year each for softwoods and hardwoods.

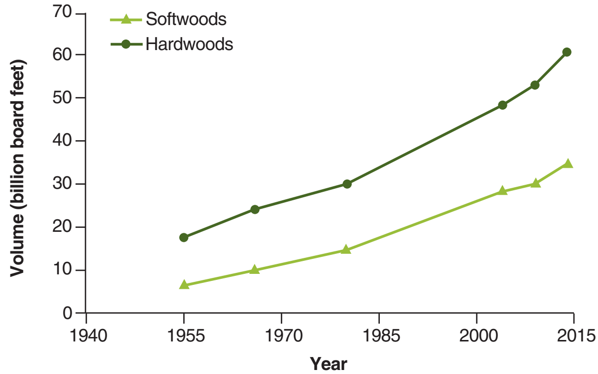

Figure 21.—Sawtimber volume on timberland by species category, Michigan.

By species, the trend in increasing sawtimber volume from 1980 to 2014 followed closely with the trend in growing-stock volume (Figs. 20, 22). Species such as red pine, black oak, and black cherry increased at least fourfold. Eastern white pine, red maple, northern white-cedar, and sugar maple increased at least twofold. Balsam fir decreased by 22 percent. There was minimal change for yellow birch and paper birch.

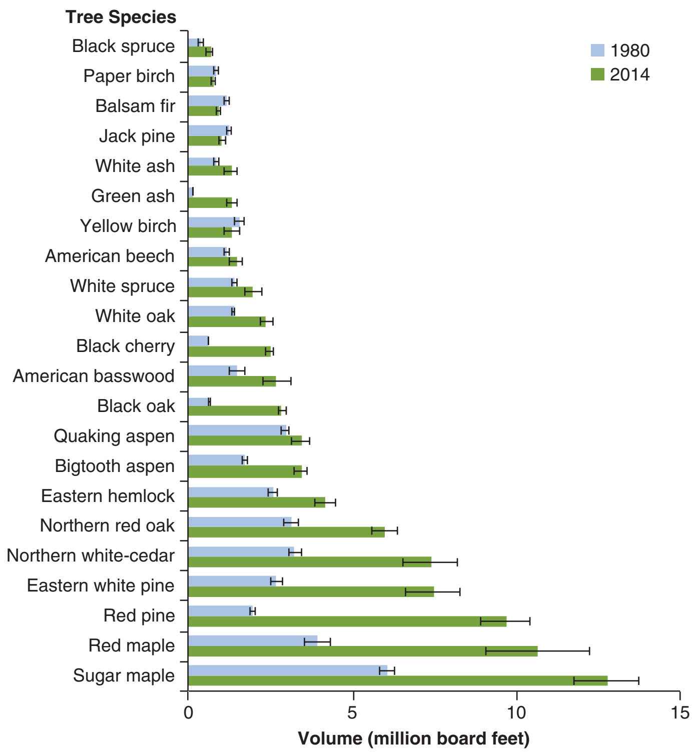

Figure 22.—Sawtimber volume on timberland for selected species, Michigan, 1980 and 2014; error bars represent 68 percent confidence interval around estimate.

Sawtimber volume has increased in every region and for every major ownership group since 1980. Forest Service land has the greatest sawtimber per-acre volume (6,373 board feet/acre) followed by private (4,979 board feet/acre) and State and local government (4,078 board feet/acre) ownership. Since 1980, the U.S. Forest Service has seen the largest gain in sawtimber per-acre volume (155 percent). On timberland, State and local government had an 89-percent increase and private ownership had an 84 percent increase.

The southern Lower Peninsula has the greatest sawtimber per-acre volume (5,811 board feet/acre) on timberland followed by the northern Lower Peninsula (4,977 board feet/acre), western Upper Peninsula (4,858 board feet/acre), and eastern Upper Peninsula (4,226 board feet/ acre). Since 1980, the greatest increase has been in the northern Lower Peninsula (143 percent). The western Upper Peninsula had the smallest increase (49 percent).

As previously stated, eastern white pine is graded 1 through 5; it has 37 percent of sawtimber volume in grade 3 with 36 percent in grades 1 and 2. Other pines (not assigned grade 4) have 91 percent of sawtimber volume in grade 3. The remaining softwoods (assigned only grades 1 or 5) have 95 percent of their sawtimber volume in grade 1. Hardwood sawtimber volume by grade appears to follow a normal distribution (Fig. 23), with 38 percent of volume in grade 3.

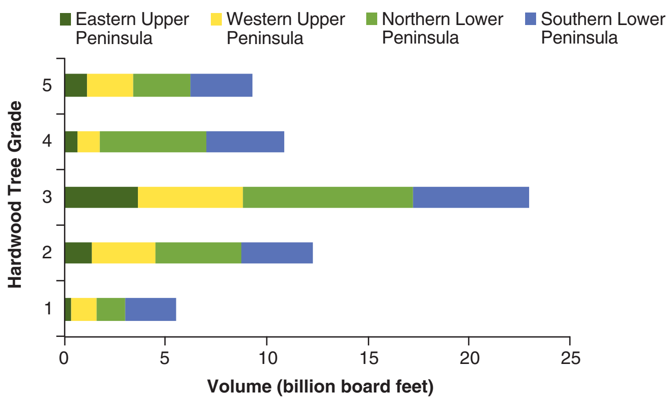

Figure 23.—Hardwood sawtimber volume on timberland by tree grade and region, Michigan, 2014.

For eastern white pine, the Upper Peninsula has 51 percent of its sawtimber volume in grades 1 and 2 versus 23 percent for the northern Lower Peninsula. The U.S. Forest Service timberland has a greater percentage of eastern white pine in grades 1 and 2 (50 percent) compared to ownership groups State and local government (39 percent) and private (31 percent). For other pines and remaining softwoods, sawtimber volume by grade did not differ appreciably among ownership groups and regions. The northern Lower Peninsula has the most timberland area and sawtimber volume in hardwoods and softwoods. Even so, the southern Lower Peninsula, with a higher proportion of slightly larger trees, has the most grade 1 hardwood sawtimber volume.

What this means

The changes in sawtimber volume were similar to those for growing-stock volume. Many late-successional species such as eastern white pine and sugar maple made substantial gains. Red maple is among the species associated with forest-cover types that have made recent gains in acreage. It is not surprising that balsam fir has experienced losses in sawtimber and growing-stock volume since 1980; this is due in part to drought and spruce budworm outbreaks (see Insects, Disease, and Decline), the mortality-to-volume rate for this species is one of the highest (Fig. 31). Since the 2009 inventory, EAB decreased ash sawtimber volume in the southern Lower Peninsula by 36 percent and increases at the State level have stopped.

Grading rules have changed over time but it is certain that we gained volume in higher grades. Given a set number of defects, larger trees receive higher grades and there were increases in the number and size of sawtimber-size trees.

Annual Net Growth

Background

Average annual net growth (growth including ingrowth minus mortality and cull) is computed by measuring trees at two points in time and determining the average annual change in volume over the period. The ratio of annual net growth to current live volume (expressed as a percent) is a useful measure for analysis. In general, a lower growth rate will be indicated by a percentage less than or equal to 1.0. Moderate growth rates are about 1.0 to 3.0; high growth rates exceed 3.0. These values vary somewhat by species. A negative number indicates that mortality is exceeding growth.

As previously mentioned, net growth, mortality, and removals estimates were improved after the 2004 inventory (see Background). For some species, the estimates of net growth varied substantially between the 2004 inventory and current methods. Here, we use 786.8 million ft^3 (analogous unadjusted estimate is 923.3 million ft^3) for the statewide estimate of net growth for growing stock on timberland for the 2004 inventory (see Pugh et. al. 2009). This estimate is based on methods aligned with the 2009 and 2014 inventories. Differences in estimates for mortality and removals were negligible so no adjustments were applied in comparisons of mortality or removals among the 2004 and more recent inventories.

Historically, estimates of change (e.g., net growth, removals, and mortality) to current volume have included land use change into and out of timberland status. With such changes included, diversions could have net growth associated with land classified as timberland in the previous inventory but the current inventory would have no associated volume due to a land use change to nontimberland. Furthermore, net growth on reversions is not limited to the change in volume from the previous to current inventory but includes the total volume of trees on conditions that reverted from nontimberland to timberland. For most analyses, this confounds comparisons of change to volume and can distort interpretations.

For the 2009 and 2014 inventories, we investigate the ratio of change to current volume on forest land where the conditions are forest in the previous and current inventory (forest-to-forest) or on timberland where the conditions are timberland in the previous and current inventory (timberland-to-timberland). Comparisons involving earlier inventories will include land use change. The type of comparison will be noted. In this section on annual net growth, estimates associated with forest land include all trees at least 5 inches d.b.h. and estimates associated with timberland are limited to growing-stock trees.

Estimates of net growth, mortality, and removals for the 2009 inventory cover measurements from 2000-2004 to 2005-2009, a nominal 5-year window. Analogous estimates for the 2014 inventory cover measurements from 2005-2009 to 2009-2014. This differs from the 10 years or more covered in previous inventories.

Pugh et al. (2012) provided ratios of net growth to current volume on timberland-to-timberland observations for the 2009 inventory. A mistake in the code used to produce the estimates included land use change from nontimberland to timberland in the numerator. This resulted in inflated estimates. The previously published and corrected estimates for the 2009 inventory are found in appendix 5.

What we found

For the 2014 inventory, average annual net growth of trees on forest land was 759.2 million ft^3 and average annual net growth of growing stock on timberland was 674.3 million ft^3. The annual net growth estimate of 759.2 million ft^3 is about 2.0 percent of current volume on forest land. In comparison, Minnesota and Wisconsin have values of 1.8 and 2.4 percent, respectively. For Michigan, 64 percent of the net growth was in hardwoods and 68 percent was in private ownership.

From 1955 to 1980, annual net growth of growing stock on timberland increased from 492.6 to 779.1 million ft^3 (Figs. 24, 25). Since1980, annual net growth changed little until a decrease in the 2009 inventory. Since 2009, there has been no practical change in total average annual net growth. However, net growth for trees on forest land rose 12 percent from the 2009 to 2014 inventory (623.9 to 696.8 million ft^3) when disregarding reversions. In contrast, reversion growth declined by 53 percent due to overestimation in the 2009 inventory. Some reversions in the 1990s to early 2000s were not identified until the 2009 inventory (Pugh 2013).

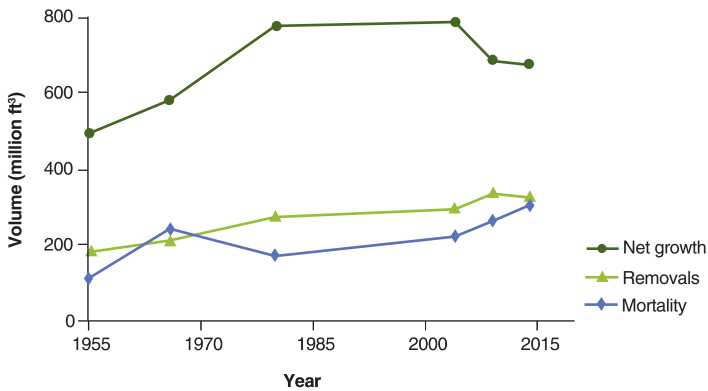

Figure 24.—Net growth, removals (all), and mortality of growing stock on timberland, Michigan. Estimates for net growth and mortality before 1980 and estimates of removals before 1993 are for a single year compared to an average over an inventory period for the more recent inventories.

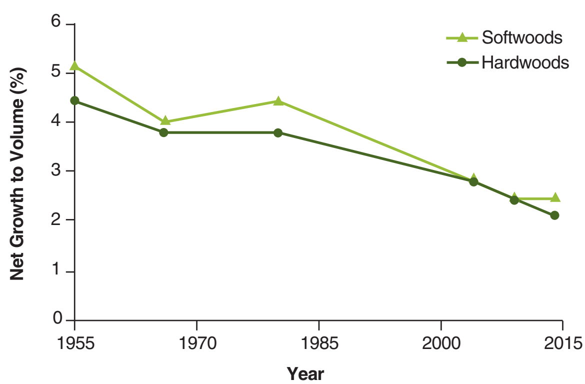

Figure 25.—Ratio (percent) of net growth to current volume for growing stock on timberland by species category, Michigan. Estimates before 1980 are for a single year as opposed to an average over an inventory period for the more recent inventories. Estimates include land use change into and out of timberland.

Since the 2009 inventory, net growth on forest land decreased by 17 percent on private ownership in the southern Lower Peninsula where 86 percent of forest land is in private ownership. Omitting ash, the analogous estimate indicates a 14 percent increase in net growth. In the southern Lower Peninsula where EAB has been established the longest, 90 percent of ash volume and 88 percent of mortality are on private land. The eastern Upper Peninsula experienced a 13 percent increase in net growth on forest land where net growth increased by 50 percent on State and local government ownership. State and local government own 28 percent of forest land in the eastern Upper Peninsula. Increases in net growth for eastern white pine, eastern hemlock, and balsam fir accounted for nearly 80 percent of the overall increase with large gains in live growth being the most influential component followed by decreases in mortality and increases in ingrowth.

Average annual net growth to current volume varies geographically (Fig. 26). Since the 2009 inventory, the southern Lower Peninsula experienced a decrease but the ratio for the eastern Upper Peninsula increased. Following trends in average annual net growth since 2009, the ratio increased substantially on State and local government in the eastern Upper Peninsula (1.1 to 1.5 percent) and decreased on private in the southern Lower Peninsula (2.5 to 2.0 percent). Disregarding ash in the 2014 inventory, the southern Lower Peninsula has the highest ratio at 2.8 percent (1.9 percent with ash) followed by the northern Lower Peninsula (2.6 percent), eastern Upper Peninsula (1.8 percent), and western Upper Peninsula (1.6 percent).

Currently statewide, land under private ownership has the highest average annual net growth to current volume on forest land (2.2 percent), followed by State and local government (2.0 percent), and the U.S. Forest Service lands (1.7 percent). There have been substantial decreases since 1980. For 1980, the best estimates available for growing stock on timberland (include land use change) are 5.6 percent for the U.S. Forest Service, 3.8 percent for State and local government, and 3.6 percent for private.

Per-acre average annual net growth of trees on forest land is highest for the northern Lower Peninsula at 43 ft^3/acre followed by the southern Lower Peninsula at 38 ft^3/acre. The rate for the Upper Peninsula is 28 ft^3/acre. Among ownerships, private land has the highest estimate (38 ft^3/acre), followed by the U.S. Forest Service (34 ft^3/acre) and State and local government (30 ft^3/acre).

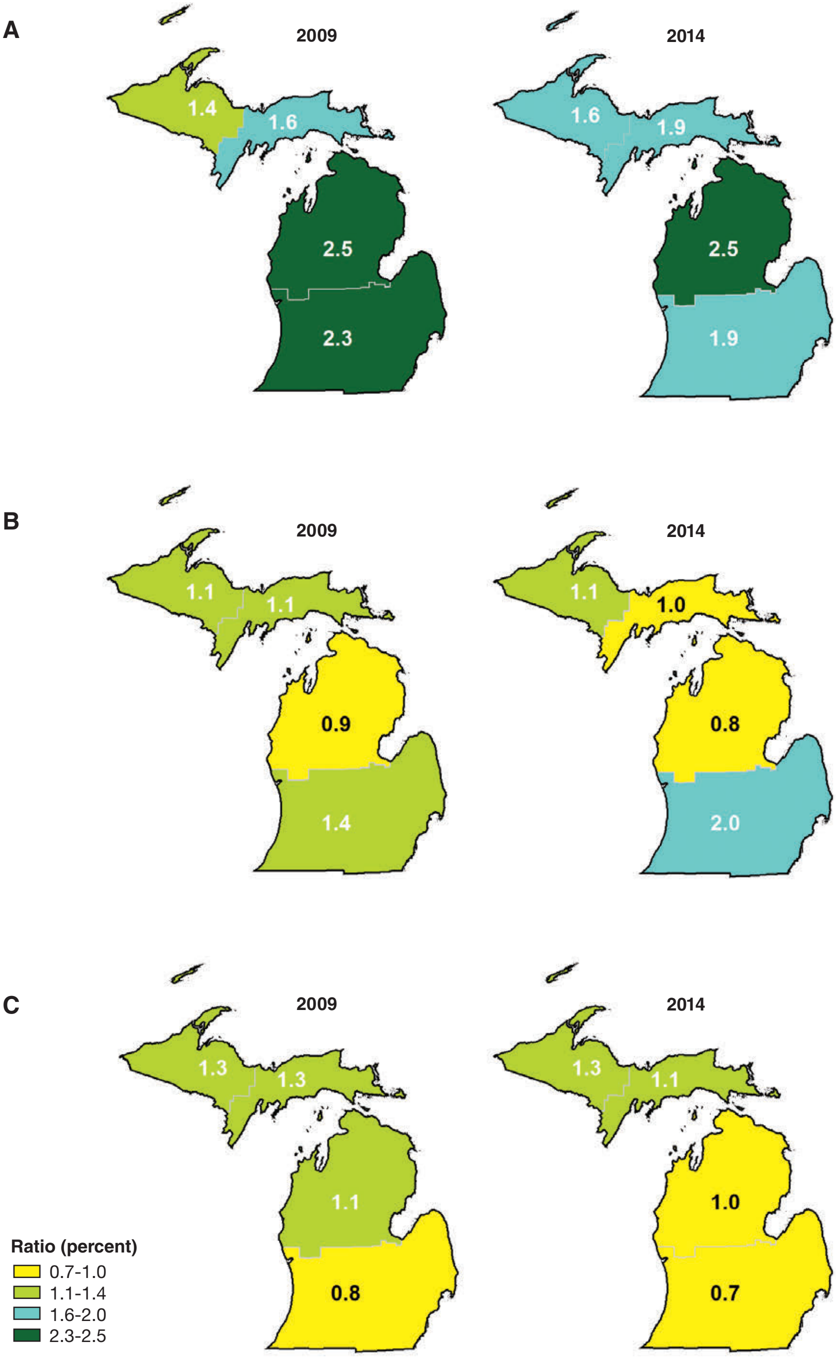

Figure 26.—Ratio (percent) of average annual net growth to current volume on forest land (A); average annual mortality to current volume on forest land (B); and average annual harvest removals to current volume on timberland (C) for trees at least 5 inches d.b.h., Michigan, 2009 and 2014. Estimates based on forest-to-forest or timberland-to-timberland observations. For data source and description of this map, see appendix 2.

For the 2014 inventory, the species shown in Figures 27 and 28 accounted for 86 percent of the average annual net growth of trees on forest land. Every ash species, paper birch, yellow birch, and American beech each experienced negative net growth and negative net growth to current volume (forest land-to-forest land) due to high amounts of mortality. Eastern white pine (3.3 percent) and northern red oak (3.1 percent) each had a high average annual rate of net growth to current volume and each remaining species had a moderate rate.

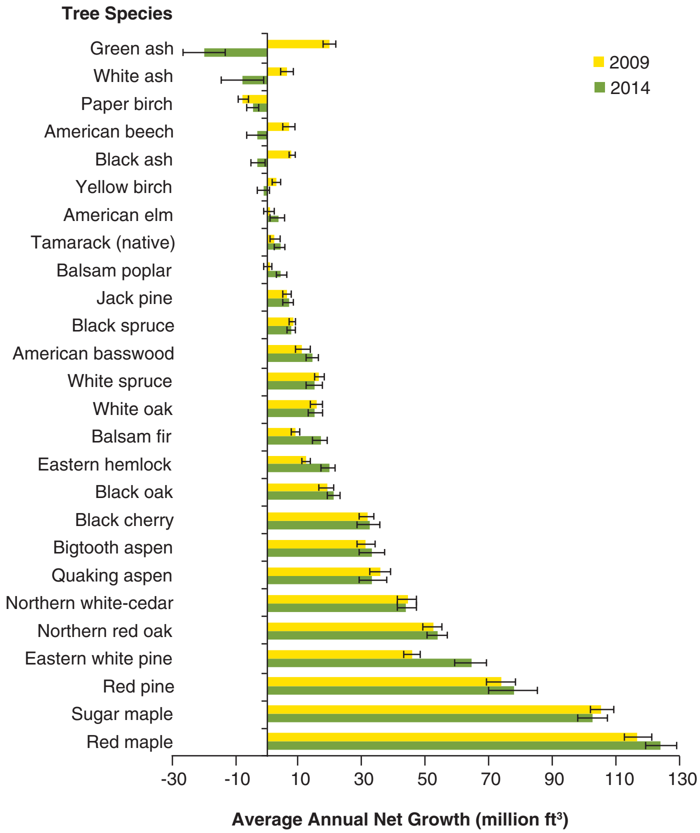

Figure 27.—Average annual net growth for trees (at least 5 inches d.b.h.) on forest land for selected species, Michigan, 2009 and 2014; error bars represent 68 percent confidence interval around estimate.

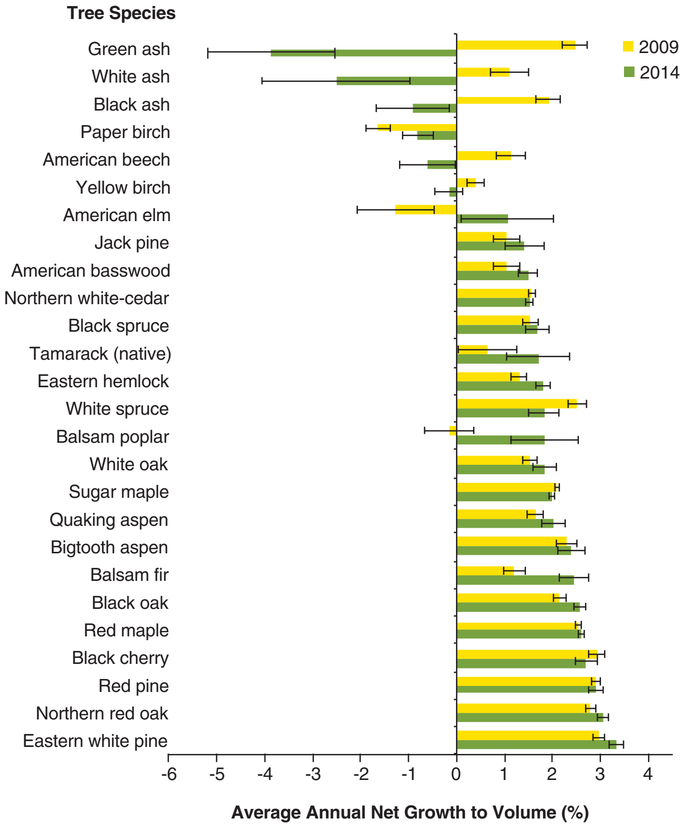

Figure 28.—Ratio (percent) of average annual net growth to current volume for trees (at least 5 inches d.b.h.) on forest land for selected species, Michigan, 2009 and 2014. Estimates based on forest land-to-forest land observations; error bars represent 68 percent confidence interval around estimate,

From the 2009 to 2014 inventory, statewide average annual net growth of trees to current volume on forest land remained constant at 2.0 percent. But the ratio changed considerably for some species. Large increases in mortality dropped the ratio for every ash species, American beech, yellow birch, and white spruce (see Annual Mortality). The ratio increased for eastern white pine, northern red oak, black oak, balsam fir, balsam poplar, eastern hemlock, American elm, and paper birch. An increase in live tree growth and a decrease in mortality benefitted northern red oak, black oak, and paper birch. An increase in live tree growth favored eastern hemlock and eastern white pine. Also, eastern white pine gained growth associated with reversions to forest land. Less mortality and increased ingrowth raised net growth for American elm. Balsam fir gained from a combination of increased ingrowth, increased live tree growth, and decreased mortality. A decrease in mortality favored balsam poplar.

What this means

Analyzing growth provides information on forest succession, disturbance, sustainability, and the ability of a species to grow well. Overall, Michigan's forests continue to mature and add volume. With maturation comes a lower rate of growth. Fortunately, net growth to volume remains moderate to high, evidence of the vitality of Michigan's forests.

Disregarding reversions, net growth rose 12 percent since the 2009 inventory. This includes the increased mortality of ash since 2009. Excluding reversions and ash, net growth rose 19 percent since the 2009 inventory. Species such as eastern white pine, eastern hemlock, balsam fir, northern red oak, and black oak gained substantially from increases in live growth.

Since 2009, mortality of ash from EAB has been the greatest factor decreasing average annual net growth to current volume for the southern Lower Peninsula, especially on private land where most ash resides. Otherwise, the region has the highest rate of net growth. This is not a surprise given the more productive climate and soils in this region. The southern Lower Peninsula has also experienced substantial increases in forest land over the last few decades. We expect the ratios for other regions to be impacted as EAB intensifies across the rest of Michigan.

Since the 1980s, the increase in volume and decrease in net growth is most evident on U.S. Forest Service land. The National Forests have been unable to harvest like other ownership groups due to a number of factors (Bosworth and Brown 2007, Keele et al. 2006, U.S. Forest Service 2002). This is contributing to decreases in net growth on these lands due to higher stocking and factors such as an increase in mature stands compared to other ownerships.

Annual Mortality

Background

Mortality is a natural part of forest stand development. A number of biotic (e.g., disease, insects, animals, and competing plants) and abiotic (e.g., wind, fire, drought, floods, and air pollution) factors contribute to mortality. Trees cut by harvesting or land clearing are considered removals and are not included in mortality estimates. Mortality can be the result of numerous factors over many years, so it is often difficult to pinpoint the cause of death. Drought can weaken trees and make them susceptible to pests years later. FIA plots are revisited cyclically, so it can be difficult to identify causes of mortality that occurred years before a plot visit. Mortality is a concern when it surpasses the growth and regeneration capacity of the forest or it creates potential dangers such as fire.

Here, we look at average annual mortality and the ratio of average annual mortality to current live volume (percent). Comparisons across decades include growing-stock volume from timberland (land use change included). Otherwise, we examine mortality of trees at least 5 inches d.b.h. on forest land. Lower mortality rates are indicated with values less than or equal to 1.0. Moderate rates of mortality are about 1.0 to 3.0; high mortality rates exceed 3.0. These guides can vary somewhat by species.

What we found

For the 2014 inventory, average annual mortality of trees on forest land was 390.8 million ft^3 and average annual mortality of growing stock on timberland was 303.3 million ft^3. This is about 1.1 percent of live volume on forest land and 1.0 percent of growing-stock volume on timberland in 2014. Except for a spike upward in 1966, average annual mortality of growing stock to current volume on timberland has remained fairly constant and low (0.8 to 1.0 percent, excluding 1966 at 1.6 percent) since 1955 (Fig. 29).

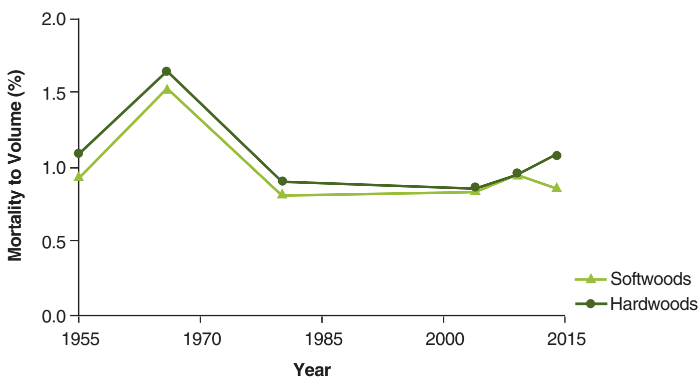

Figure 29.—Ratio (percent) of mortality to current volume for growing stock on timberland by species category, Michigan. Estimates before 1980 are for a single year as opposed to an average over an inventory period for the more recent inventories. Estimates include land use change into and out of timberland.

On Michigan's forest land, 76 percent of the mortality was in hardwoods and 65 percent was in private ownership. Average annual mortality to current volume is highest in the southern Lower Peninsula (2.0 percent) primarily due to high ash mortality caused by EAB (Fig 26). Mortality to current volume was 17 percent for ash in the southern Lower Peninsula. Likewise, average annual mortality of trees per acre on forest land is highest in the southern Lower Peninsula (39 ft^3/acre) followed by the western Upper Peninsula, eastern Upper Peninsula, and northern Lower Peninsula at 19, 16, and 14 ft^3, respectively.

Average annual mortality remains low at the State level but it has been rising since the early 2000s (Fig. 24). On forest land from the 2009 to 2014 inventory, an overall 13 percent increase occurred. Hardwoods experienced a 20 percent increase and softwoods held steady with a 3 percent decrease. Excluding ash, the overall mortality estimate decreases by nearly 5 percent from 2009 to 2014 at the State level.

Since the 2009 inventory, only the southern Lower Peninsula experienced an increase in mortality (65 percent). Disregarding ash, mortality remained stable in the southern Lower Peninsula and dropped 17 percent in the northern Lower Peninsula. With or without ash, there was no notable change in the Upper Peninsula. Considering all species statewide, private ownership experienced a mortality increase (21 percent). Omitting ash, private (-6 percent) and State and local government (-11 percent) experienced a mortality decrease.

The most common sources of mortality throughout the State were insects (17 percent), weather (8 percent), and disease (8 percent).The cause of mortality was identified most often in the southern Lower Peninsula (70 percent identified) where 41 percent of the instances were attributed to insects. The primary cause of mortality could not be determined in 62 percent of the instances for the 2014 inventory.

The species displayed in Figures 30 and 31 accounted for 96 percent of the average annual mortality of trees on forest land for the 2014 inventory. Quaking aspen and bigtooth aspen had high amounts of average annual mortality but have moderate rates of mortality to current volume. Green ash, white ash, black ash, American elm, balsam fir, and paper birch have the highest rates of annual mortality to current volume and had corresponding high amounts of average annual mortality. Balsam poplar, American beech, jack pine, tamarack, yellow birch, white spruce, black spruce, and black cherry have moderate rates of annual mortality to current volume.

Moderate to high mortality for balsam fir, American elm, balsam poplar, quaking aspen, jack pine, paper birch, and yellow birch have contributed to reductions in growing-stock volume since 1980 (Fig. 20). These species also had significant reductions in number of trees for certain size classes (Table 3).

Average annual mortality increased nearly five times for green ash and nearly three times for white ash since the 2009 inventory (Fig. 30). The estimate more than doubled for American beech and black ash. The rate of average annual mortality to current volume increased for each ash species, American beech, yellow birch, and white spruce since 2009 (Fig. 31). The rate dropped for northern red oak, black oak, balsam poplar, paper birch, balsam fir, and American elm.

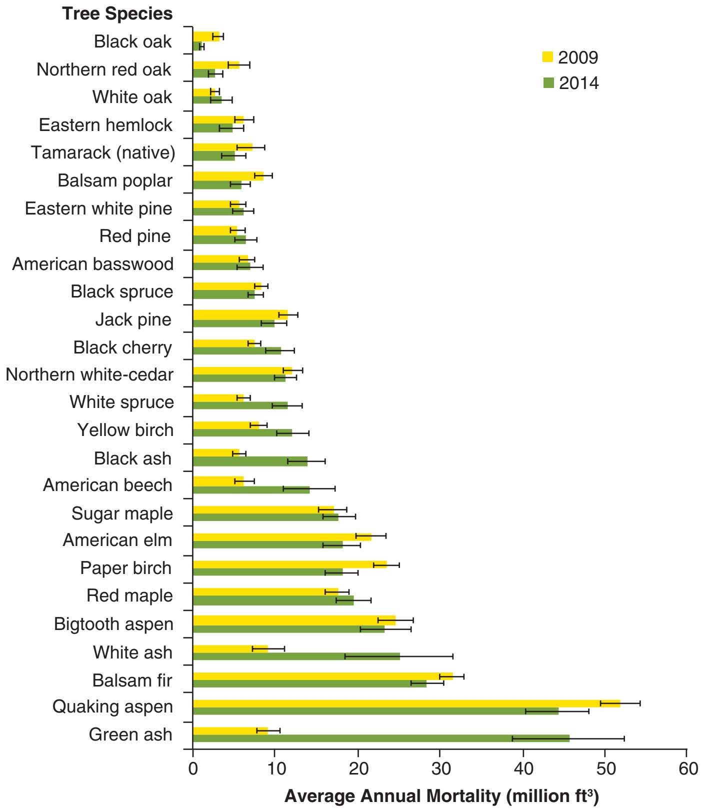

Figure 30.—Average annual mortality for trees (at least 5 inches d.b.h.) on forest land for selected species, Michigan, 2009 and 2014; error bars represent 68 percent confidence interval around estimate.

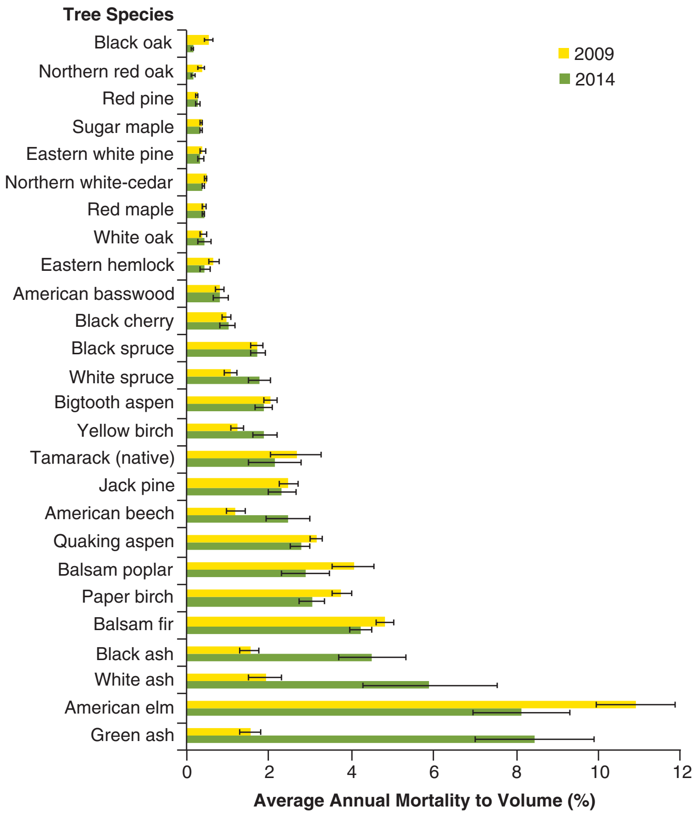

Figure 31.—Ratio (percent) of average annual mortality to current volume for trees (at least 5 inches d.b.h.) on forest land for selected species, Michigan, 2009 and 2014. Estimates based on forest land-to-forest land observations; error bars represent 68 percent confidence interval around estimate.

What this means

Michigan has been fortunate to have low rates of mortality. Factors such as succession, drought, and pathogens contribute to mortality. Higher rates of mortality to volume are expected in short-lived, early successional species such as jack pine, paper birch, and aspens as forests mature. The declines in volume and number of trees might be a management concern from a perspective of wood fiber and maintenance of these types.

In cases where forests are overmature and trees are succumbing to various damage agents, forest types are often associated with species exhibiting moderate or high rates of mortality. Most of the high rate in balsam fir and moderate rates in black and white spruce likely are due to droughts combined with spruce budworm attacks primarily on mature to overmature stands (see Insects, Disease, and Decline). Wisconsin and Minnesota have about the same rate of average annual mortality to current volume for balsam fir at 4.2 and 3.6 percent, respectively. At the State level, the ratio of average annual mortality to current volume on forest land is 1.3 and 1.9 percent for Wisconsin and Minnesota, respectively.

Average annual mortality has been increasing since the early 2000s but the overall rate of mortality to current volume has held fairly constant. The same general trend has been observed in Wisconsin and Minnesota. In Michigan, consecutive intervals of drought since the late 1990s have predisposed species in some areas to higher rates of mortality (see Insects, Disease, and Decline). Nonnative pests and disease such as EAB and beech bark disease (BBD), the primary killing agent of American beech, have substantially increased mortality of their respective hosts. Moreover, EAB has noticeably increased the statewide estimate inclusive of all species; excluding ash, the statewide estimate dropped nearly 5 percent since 2009.

Annual Removals

Background

Of the three components of change (net growth, removals, and mortality), removals is the most directly tied to human activity and is thus the most responsive to changing socioeconomic conditions. Changes in demand for wood play a key role in removals. The removals estimate includes harvest removals (utilized and not utilized) and diversion removals. Harvest removals include utilized trees and trees killed (cut or not cut) as a result of harvest operations (including land clearing) but not utilized. Diversion removals associated with timberland occur when living trees are removed from the timberland base due to land use change. Timberland can change to less productive or reserved forest land or nonforest. Likewise, diversion removals associated with forest land occur when forest land changes to nonforest land and living trees persist. Among the estimates of change, removals has the least number of nonzero FIA plot observations, so the estimates are inherently less precise.

The timber product output (TPO) study provides another estimate of removals that is based on a survey of known primary wood-using mills in Michigan, the most recent TPO mill surveys from other states that reported processing wood harvested from Michigan, and regional harvest utilizations studies (see Timber Product Output). FIA plot observations provide an alternative measure of growing-stock removals from timberland. These alternatives often produce different estimates of growing-stock removals from timberland.

For the 2009 and 2014 inventories, we primarily focus on average annual harvest removals and the ratio of average annual harvest removals to current live volume (percent) for trees at least 5 inches d.b.h. on timberland (timberland-to-timberland). Comparisons across decades focus on all removals of growing stock from timberland, which includes land use change. When average annual removals are compared to current standing volume (ratio in percent), lower removal rates are indicated with values less than or equal to 1.0. Moderate removals are about 1.0 to 3.0; high removals exceed 3.0.

What we found

Total average annual removals (all removals) of trees at least 5 inches d.b.h. from timberland totaled 364.7 million ft^3 for the 2014 inventory (Fig. 24). Ninety-seven percent, or 352.9 million ft^3, of this total was average annual harvest removals. This harvest estimate is essentially equivalent to the 350.5 million ft^3 of the 2009 inventory.

For the 2014 inventory, the ratio of average annual harvest removals to current volume is approximately 1.1 percent. The average annual harvest removals are about 50 percent of average annual net growth (timberland-to-timberland). Seventy-three percent of the harvest removals was in hardwoods and 68 percent was in private ownership. Although harvest removals on public ownership account for only 32 percent of total harvest removals, 53 percent of the softwood harvest removals came from public land. Forty-six percent of the softwood volume (trees at least 5 inches d.b.h.) is on public timberland.

The TPO estimates of harvest removals (growing stock on timberland) have ranged from 168 million ft^3 in 1965 to 354 million ft^3 in 1994 (see Timber Product Output). TPO estimates generally have been higher than estimates of average annual removals from the 1993 and 2004 FIA plot inventories. The average TPO harvest removals estimate of growing stock from timberland for 2008 and 2010 was 315 million ft^3, very close to the analogous estimates of 310 and 313 million ft^3 derived from FIA plot observations for the 2009 and 2014 inventory, respectively.

From 1955 (177.5 million ft^3) to 1980 (274.6 million ft^3), total annual removals of growing stock on timberland (includes land use change) increased from 1.5 to 2.4 percent per year (Fig. 24). From 1980 to 2004, total removals remained steady or increased slightly. During the 2009 inventory, total annual removals increased an average of 3.0 percent per year. There was no discernable change in total average annual removals between the 2009 and 2014 inventory. Total annual removals were the lowest in 1955, but the ratio of removals to volume was at its peak (1.7 percent) (Fig. 32). There was much less volume in 1955.

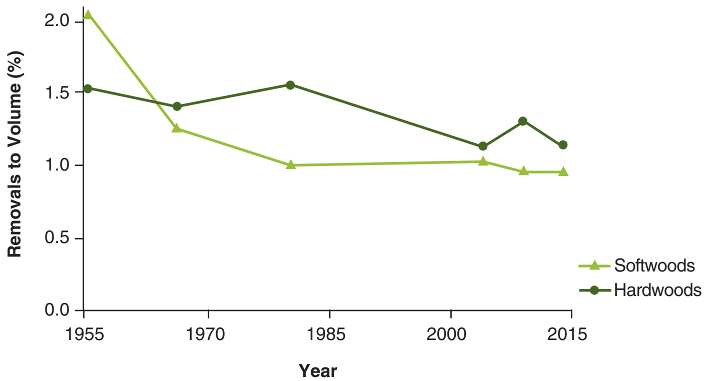

Figure 32.—Ratio (percent) of removals to current volume for growing stock on timberland by species category, Michigan. Estimates before 2004 are for a single year as opposed to an average over an inventory period for the more recent inventories. Estimates include land use change into and out of timberland.

Average annual harvest removals to current volume varies geographically (Fig. 26) with larger ratios in the Upper Peninsula (1.2 percent) and northern Lower Peninsula (1.0 percent) compared to the southern Lower Peninsula (0.7 percent). Average annual harvest removals per acre on timberland were 23, 18, 17, and 14 ft^3 for the western Upper Peninsula, eastern Upper Peninsula, northern Lower Peninsula, and southern Lower Peninsula, respectively. Harvest removals in the northern Lower Peninsula (124.9 million ft^3) were greater than in other regions. The western Upper Peninsula (101.8 million ft^3) has the next highest harvest removals followed by the eastern Upper Peninsula (72.2 million ft^3) and southern Lower Peninsula (54.1 million ft^3).

The ratio of average annual harvest removals to current volume varies among ownership groups. State and local government lands (1.5 percent) had the highest rate followed by private (1.1 percent) and the U.S. Forest Service (0.4 percent). State and local government had a 50 percent increase and private ownership had a 12 percent decrease in harvest removals from the 2009 to 2014 inventory. Variability in the harvest estimates makes it difficult to identify change.

Species displayed in Figures 33 and 34 accounted for 92 percent of the average annual harvest on timberland for the 2014 inventory. Sugar maple had the most average annual harvest removals but its rate of harvest removals to current volume was just above average at 1.2 percent. Jack pine has a high rate of harvest removals to volume (2.8 percent). The intolerant and/or fast growing pioneer species, such as aspens, birches, and balsam fir, have moderate rates. The rate for American beech is higher than rates for most species. Most other prominent species have low rates. The rate for red pine increased from 0.9 to 1.7 percent from the 2009 to 2014 inventory. There was also a twofold increase in average annual harvest removals for red pine (Fig. 33). In contrast, average annual harvest removals decreased by 38 percent for jack pine.

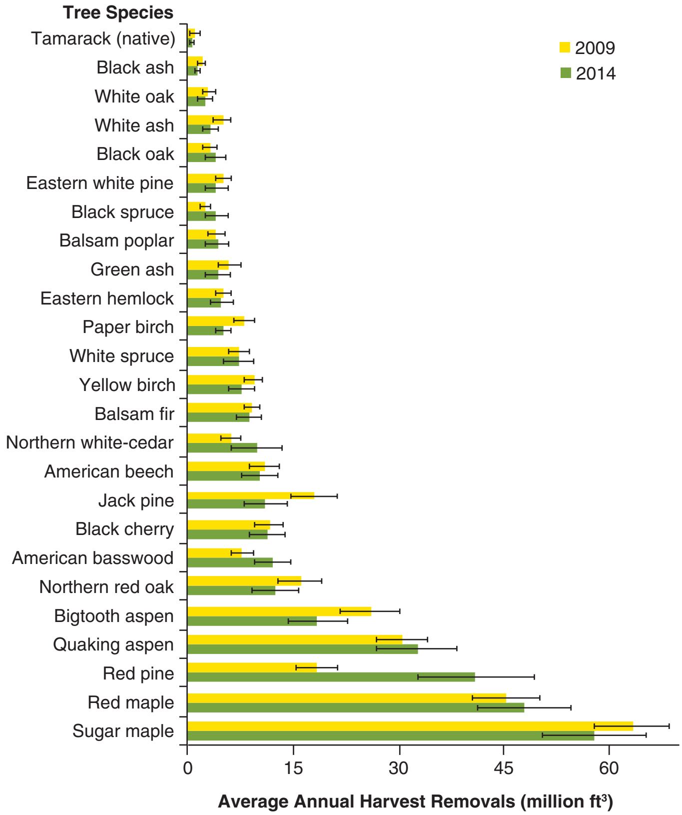

Figure 33.—Average annual harvest removals for trees (at least 5 inches d.b.h.) on timberland for selected species, Michigan, 2009 and 2014; error bars represent 68 percent confidence interval around estimate.

As mentioned previously, total removals not only takes into consideration what was actually removed off site but also includes land use change and trees killed (cut or not cut) as a result of harvest operations but not utilized. Trees killed as a result of harvest operations, silvicultural, or land clearing activity, but not utilized are a component of harvest removals and account for 4 percent of removals. Ninety-two percent of the average annual removals associated with timberland were due to harvesting and removal from the site. Slightly less than 3 percent of the average annual removals were in trees not removed but rather left standing as the land was diverted to nonforest. Likewise, diversion to less productive forest land was less than 1 percent of total removals. Less than 1 percent was associated with diversion to reserved forest land.

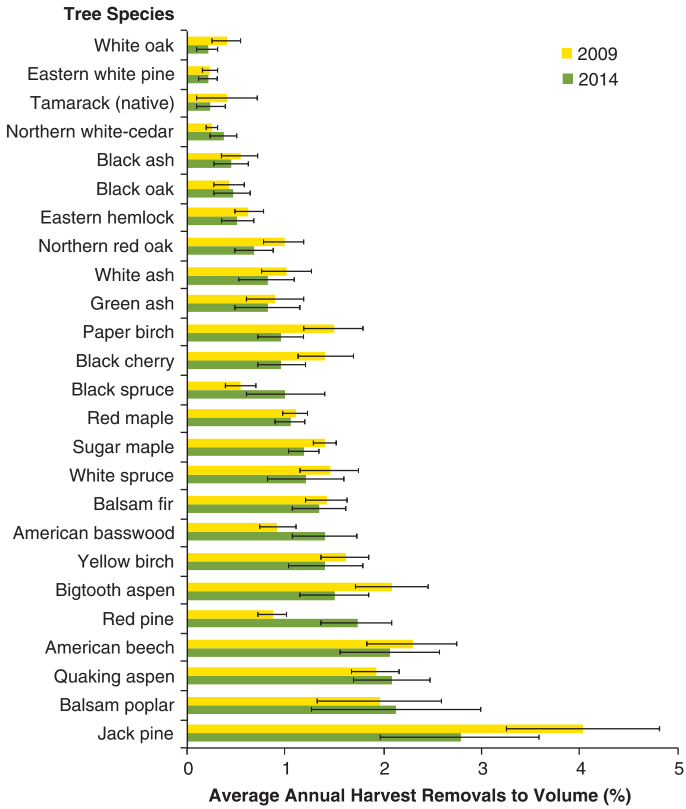

Figure 34.—Ratio (percent) of average annual harvest removals to current volume for trees (at least 5 inches d.b.h.) on timberland for selected species, Michigan, 2009 and 2014. Estimates based on timberland-to-timberland observations; error bars represent 68 percent confidence interval around estimate.

What this means

Removals are affected by biological and social factors. Harvesting is not a top priority for most private owners (Butler et al. 2016) or for public owners like the U.S. Forest Service. Since the 1950s, the ratio of harvest removals to volume has been low for Michigan. The statewide ratio of harvest removals to volume is currently 1.1 percent (timberland-to-timberland). Minnesota and Wisconsin have percentages of 1.4 and 1.1, respectively.

The latest TPO and plot-derived estimates are essentially equal. In the past, the plot-derived estimates have been less than the TPO estimates. It is common that estimates derived from these different methods vary at times. Harvest removals and mortality are events that happen at specific times but the plots are measured within windows of time. Harvests could have occurred from 2005 through 2009 during the 2009 inventory and just recently been recorded in the 2014 inventory from 2009 through 2014. Another consideration is the fact that FIA has the least number of nonzero plot observations for removals, so there is inherently more variability in the estimates. Understanding these factors helps explain how these different methods can result in different estimates.

The ratio of average annual harvest removals to current volume for different species reflects the attributes and management practices associated with the species. Shade-tolerant species such as sugar maple are expected to have lower rates for removals to volume than intolerant pioneer species such as quaking aspen. Intolerant species do not live as long so the rotation cycle for harvesting these species is shorter. Also, the species attributes lend themselves to practices that remove some or all of the trees when harvesting to promote regeneration. Species such as balsam poplar, balsam fir, jack pine, and paper birch also have moderate or high rates of mortality. Some of the removals for these species could be an attempt to "capture mortality" or harvest the trees before they die.

The increase in red pine harvest removals since the 2009 inventory is primarily due to the increase in harvests on State and local government lands. Red pine harvest removals at 26.5 million ft^3 per year accounted for 27 percent of total average annual harvest removals (96.3 million ft^3) on State and local government ownership in the 2014 inventory. There was also more than a threefold increase in red pine annual harvests on U.S. Forest Service land, but these lands only account for 11 percent of the total red pine annual harvest removals (4.5 million ft^3).

Net Growth to Removals

Background

One measure of sustainability is the ratio of net growth to removals. A ratio greater than 1 indicates the volume of the species is increasing; a ratio less than 1 indicates the volume is decreasing. It is not always beneficial to maintain high ratios of net growth to removals.

For the 2009 and 2014 inventories, we primarily focus on average annual net growth to average annual harvest removals (percent) for trees at least 5 inches d.b.h. on timberland (timberland-to-timberland). Comparisons across decades focus on all removals of growing stock from timberland, which includes land use change.

What we found

The ratio of net growth to harvest removals for the 2014 inventory is 2.0, indicating that volume is increasing at a moderate to high rate. The 2009 inventory had essentially the same ratio—1.8. For the current inventory, every ash species, paper birch, American beech, and yellow birch have negative ratios due to negative net growth (Fig. 35). Moderate to high mortality and harvest removal rates contribute to lower ratios for aspens, balsam fir, American beech, jack pine, paper birch, and balsam poplar (Figs. 31, 34). Species such as eastern white pine, white oak, black oak, northern red oak, northern white cedar, and eastern hemlock have moderate to very high ratios associated with moderate to high net growth and low harvest removal rates (Fig. 28).

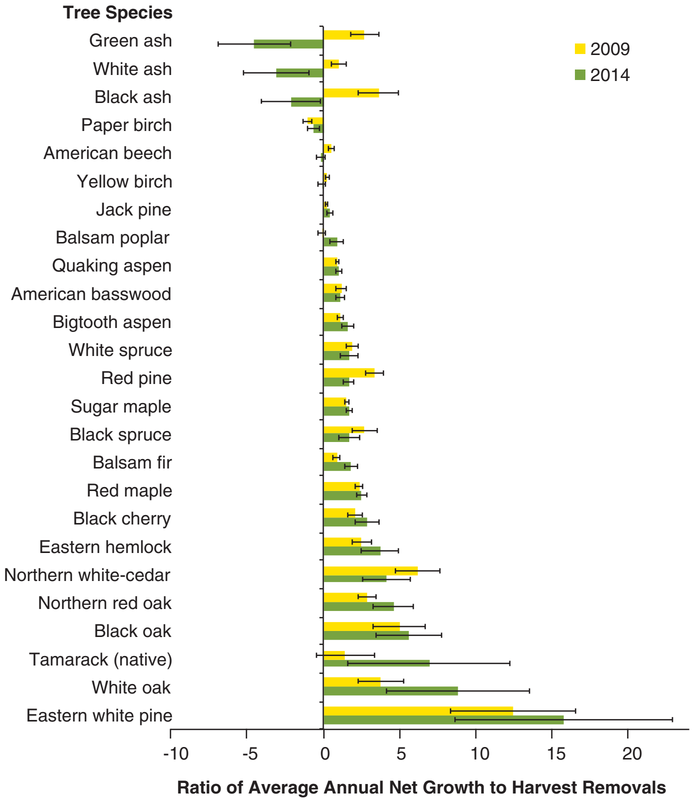

Figure 35.—Ratio of average annual net growth to harvest removals for trees at least 5 inches d.b.h. on timberland for selected species, Michigan, 2009 and 2014. Estimates based on timberland-to-timberland observations; error bars represent 68 percent confidence interval around estimate.

Since the 2009 inventory, the ratio for red pine dropped due to a substantial increase in harvest removals and the ratio for balsam fir increased due to an increase in net growth. Ratios among ash species ranged from moderate to high in the 2009 inventory but they have collapsed due to large increases in mortality.

From 1955 to 2004, the net growth to total removals ratio for growing-stock trees remained nearly constant from 2.7 to 2.8 (includes land use change; Fig. 36). From 2004 to 2009, net growth decreased by an average 2.5 percent per year and total removals increased by 3.0 percent per year resulting in a lower ratio of 2.1. Net growth and total removals for growing stock on timberland remain steady since the 2009 inventory maintaining the ratio of net growth to total removals at 2.1 for the 2014 inventory.

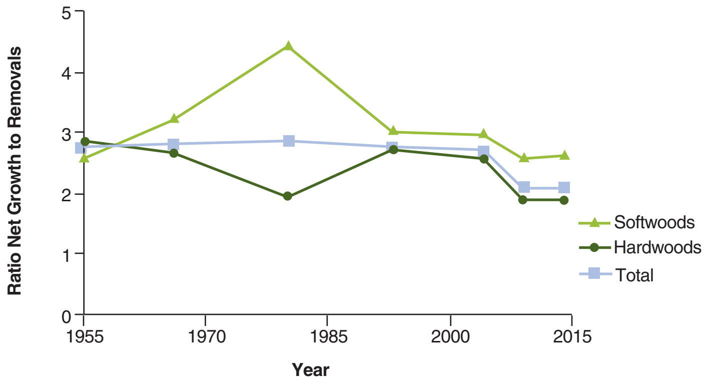

Figure 36.—Ratio of net growth to total removals for growing stock on timberland by species category, Michigan. Estimates include land use change into and out of timberland.

Ratios of net growth to harvest removals for trees on timberland are similar for the western Upper Peninsula and eastern Upper Peninsula at 1.3 and 1.7, respectively, for the 2014 inventory. The ratios for the northern Lower Peninsula and southern Lower Peninsula are higher and similar at 2.5 and 2.6, respectively.

The U.S. Forest Service land has the highest ratio of net growth to harvest removals at 5.0 followed by privately owned land at 2.0 and State and local government at 1.3. The U.S. Forest Service's lower rate of annual harvest removals to current volume is a major factor in its high ratio of net growth to harvest removals.

Equivalent ratios of net growth to removals can be based on various conditions. Compared to more recent years, the 1955 inventory had the highest ratios of annual net growth and removals to current volume for growing stock on timberland (Figs. 25, 32). The 1955 inventory was also associated with the least amount of growing-stock volume (Fig. 17) on a high amount of forest land (Fig. 2), and mortality was relatively low (Fig. 29). Despite changing conditions from 1955 through 2004, the overall ratio held relatively constant.

What this means

Even with the small drop from historical levels since the 2004 inventory, the ratio of net growth to removals is still at a moderate to high level. Michigan's ratio of net growth to harvest removals for trees on timberland (2.0) does not differ considerably from ratios for Wisconsin (1.7) and Minnesota (1.8). At the State level, Michigan has had relatively low removals and mortality rates but high growth rates.

Since the ratios differ substantially by region and owner, it is important to consider these differences in management decisions. The western Upper Peninsula has a low ratio of 1.3 but the ratio for the U.S. Forest Service in the western Upper Peninsula is 2.8.

Low mortality and high growth rates help maintain a sustained yield, and a high ratio is generally better than a low one. This is only one indicator of a sustained yield as it can be beneficial to lower the ratio of net growth to removals. For example, forest health might be improved if removals were increased in some jack pine stands even though they might already be experiencing low ratios of net growth to removals. A high ratio of net growth to removals could result in forest health issues over time, especially for certain species. The objectives of land managers also determine the appropriate ratio of net growth to removals. If the primary objective is timber production, a long-term ratio of about 1 is more appropriate than a high ratio.

Many of the species with low ratios of net growth to removals are in greater demand by the wood-products industry and some have health issues. For example, jack pine, spruce, balsam fir, birch, and aspen are in high demand for the manufacture of pulp and composite products. These species also have health issues with moderate to high mortality rates. Mortality from EAB and BBD has lowered the ratios for ash and American beech. Also, nonmarket factors such as wildlife concerns can constrain the supply of species (e.g., northern white-cedar), keeping ratios high.

Forest Health Indicators

Stream in Porcupine Mountains State Park, MI. Photo by Dave Kenyon, MI DNR, used with permission.

Insects, Disease, and Decline

Background

Forest health, structure, and composition are influenced by the interaction of biotic and abiotic elements. Monitoring the status of these factors provides a measure of forest health and is crucial in assessing conditions and trends in Michigan's forests. Changes to our forest ecosystems often are observed when pests, disease, and other adverse environmental conditions combine. Abiotic environmental factors such as drought, extreme wetness, windstorms, late spring frosts, pollution, and soil properties that affect nutrient availability, moisture content, and aeration influence the effects of pests and disease and predispose trees to decline. A list of insects and diseases mentioned in this report is included in appendix 6.

Frequent drought events since the 1980s have contributed to declines in some susceptible tree species. Severe and extreme droughts as characterized by the Palmer Drought Severity Index (Palmer 1965) were common during the 2009 inventory. Overall, the intensity of drought was less during the 2014 inventory but it was still obvious with moderate to extreme drought in 2010 and moderate to severe drought in 2012. For more information, visit http://www.drought.gov/drought/area/mi. Declines are characterized by a gradual loss of tree growth and vigor usually accompanied by off-color leaves, early leaf drop, and crown dieback and thinning. Trees on xeric and hydric sites and short-lived species that are at or past maturity are most susceptible.

Pests that otherwise would not pose a threat to healthy trees can become a serious threat to declining trees. These pests include defoliators, wood-boring insects, and root rot fungi. A number of pests contribute to increases in tree mortality during drought. Oak is affected by the two-lined chestnut borer, paper birch by the bronze birch borer, larch by the eastern larch beetle, balsam fir by the spruce budworm and Armillaria root rot, jack pine by the jack pine budworm, and jack and red pine saplings by diplodia blight and Armillaria root rot. Drought also can increase populations of forest defoliators such as gypsy moth, linden looper, fall cankerworm, forest tent caterpillar, jack pine budworm, and spruce budworm. In addition to many insects and diseases that have evolved over time as part of the natural life cycle of trees, there is a continuing threat from nonnative species. Nonnative species have not evolved with our forest ecosystems and may have no biological control agents. Consequently, these species can have adverse effects on the health, structure, and composition of native forest communities (Mack et al. 2000, Mooney and Cleland 2001, Parker et al. 1999). Michigan has been affected by nonnative insects and diseases such as Dutch elm disease, chestnut blight, butternut canker, gypsy moth, and, more recently, EAB, BBD, hemlock wooly adelgid, and sirex woodwasp.

There has been increased interest in the effects of deer and other cervid herbivory on the regeneration and survival of herbaceous and woody plants in forest ecosystems (Cook 2008, Cote et al. 2004). This is a particular concern when local populations of cervids are high (see Regeneration Status).

There are a number of groups that focus on monitoring forest health. Information presented in this section is derived from data from the U.S. Forest Service's FIA, National Forest Health Monitoring program, and Northeastern Area, State and Private Forestry; and MIDNR's Forest Health, Stewardship and Urban Forestry unit. There are many cooperative projects to stop or mitigate forest health issues in Michigan through mandatory and recommended management practices that effectively improve forest health.

What we found

A number of noteworthy insects and disease pathogens were active in Michigan from 2009 through 2014 (Table 6). Several declines were also reported. Damage by some insects is effectively identified with aerial surveys. Damage reports from aerial surveys are available for jack pine budworm, gypsy moth, forest tent caterpillar, spruce budworm, larch casebearer, eastern larch beetle, and others from the U.S. Forest Service's Forest Health Technology Enterprise Team (U.S. Forest Service 2015).

The native jack pine budworm is the main pest for jack pine. Budworm defoliation tends to occur in a cyclical fashion, about every 6 to 10 years. Mature stands on low quality sites are most vulnerable. Based on aerial surveys, damage by the native jack pine budworm increased from nearly no detection in 2000 to 329,600 acres in 2003. Damage gradually decreased to 509 acres in 2009. After 2009, damage fluctuated from a low of 5,300 acres in 2013 to a high of 101,600 acres in 2014. Jack pine mortality has remained steady since the 2009 inventory.

Oaks are the primary host of the nonnative gypsy moth. After minimal damage in 2001 and 2002, damage by gypsy moth increased to 148,500 acres in 2005. After 2005, damage varied but remained low through 2009 (7,900 to 113,900 acres annually). A moderate to heavy outbreak occurred in 2010 resulting in 941,900 acres of damage, an estimate comparable to the high acreages witnessed in the1980s and early 1990s. However, the outbreak quickly subsided in 2011 and remained low through 2014 (0 to 53,600 acres annually). A natural enemy complex of parasites, predators, and fungi has established and become successful at tempering outbreaks. The fungus Entomophaga maimaiga is particularly effective in cool wet spring weather. Northern red oak and black oak had noticeably lower average annual mortality since the 2009 inventory (50 and 62 percent reductions, respectively).

Table 6.—Insects, disease, and declines that have caused damage to forests, Michigan, 2014

Insects, Disease, and Declines	Identified Host
Ash decline	ash
Ash yellows	ash
Aspen decline	aspen
Beech bark disease	American beech
Diplodia shoot blight	pine
Eastern larch beetle	native tamarack
Emerald ash borer	ash
Fall webworm	hardwoods
Forest tent caterpillar	sugar maple, aspen, oak, birch, other hardwoods
Gypsy moth	oak, other hardwoods
Heterobasidion root disease	pine, spruce
Hickory wilt	hickory
Jack pine budworm	jack pine
Larch casebearer	native tamarack
Large aspen tortrix	aspen
Loopers or cankerworms	sugar maple, other hardwoods
Maple decline	sugar maple, other maple
Oak decline	northern pin oak, other oak
Oak wilt	northern red oak
Orange-humped mapleworm	maple
Pine spittlebug	pine
Spruce budworm	balsam fir, spruce
Spruce decline	spruce
Spruce needle rust	spruce
White pine decline	white pine

The native forest tent caterpillar has widespread outbreaks about every 10 to 15 years with its most notable impact on aesthetics. Its hosts include many hardwoods such as sugar maple, aspen, oaks, and birch. The last outbreak peaked in 2001 at 2.5 million acres. Damage dropped quickly to only small scattered areas in 2004. Damage remained low until 2009 (366,400 acres) through 2010 (400,700 acres). The outbreak subsided with little acreage identified in 2011 (2,300 acres) through 2012 (6,000 acres) and no damage recorded in 2013 through 2014.

Following drought and repeated defoliations by the nonnative larch casebearer in the early 2000s, the native eastern larch beetle killed 29,400 and 25,700 acres of native tamarack in 2004 and 2005, respectively. From 2006 through 2012 minimal damage was reported. Eastern larch beetle killed 2,000 and 1,200 acres of native tamarack in 2013 and 2014, respectively. Larch casebearer defoliation was identified on nearly 3,000 acres in 2014. The estimated average annual mortality for native tamarack doubled from the 2004 to 2009 inventory and has not changed appreciably since the 2009 inventory.

Mature and overmature balsam fir stands are affected most severely by the native spruce budworm, which prefers balsam fir over spruce. Outbreaks throughout the eastern United States cause extensive damage and mortality every 30 to 50 years and are part of the natural life cycle of balsam fir. The last severe outbreak occurred in the Upper Peninsula from the late 1960s to the early 1980s and in 1997, spruce budworm damaged about 48,600 acres. Damage decreased and remained low from 1999 through 2002. From 2003 through 2008, damage rose a couple times but remained less than 26,000 acres. From 2009 through 2014, more extensive damage occurred, ranging from 51,900 to 177,600 acres annually. Balsam fir and black spruce mortality has remained steady since the 2009 inventory but white spruce mortality increased nearly 86 percent. It has been over 30 years since the last severe outbreak, there have been many years of drought, and damage has risen since 2008. In 2015, the extent of damage increased substantially over the previous several years and most notably in the western Upper Peninsula (estimates not currently available). The next major outbreak is likely underway.

The nonnative EAB was first discovered near Detroit in 2002. Since then it has been found in 24 other states, Ontario, and Quebec. All major species of ash are susceptible. EAB larvae feed on the inner bark and disrupt the transport of water and nutrients. Almost all infested trees die. At this time, the Lower Peninsula is generally infested. EAB has not been discovered in seven western counties of the Upper Peninsula. Movement of hardwood firewood out of the remaining quarantined counties is prohibited. From the 2004 to 2009 inventory, the average annual mortality estimate for green ash increased nearly seven times. The estimate rose more than four times for white ash. Since the 2009 inventory, estimates increased approximately five, three, and two times for green, white, and black ash, respectively.

BBD is the result of a small, sap-feeding insect known as beech scale and at least two species of Nectria fungi (one nonnative and one native species) acting together (McCullough et al. 2005). The cause of substantial defect and mortality of American beech across the northeastern United States, BBD has been a major concern in Michigan since its discovery in 2000. At this time, BBD has spread through most of the American beech range in Michigan, which is concentrated in the western half of the northern Lower Peninsula and most of the eastern Upper Peninsula. Average annual mortality estimates for American beech increased more than five times from the 2004 to 2009 inventory and more than two times since the 2009 inventory.

Oak wilt, a fungus, is one of the most serious tree diseases in the eastern United States aggressively killing oaks. Oak wilt is widely distributed in the southern Lower Peninsula, spotty in the northern Lower Peninsula, and spotty in a few counties of the Upper Peninsula. It spreads underground through root connections and over land by sap beetles spreading spores to open tree wounds. Movement of firewood infected with the oak wilt fungus is a major concern. Treatment includes destroying infected trees and severing infected tree roots from adjoining trees.

Aspen (many areas of the Lake States), eastern white pine (north central Lower Peninsula and Hiawatha National Forest), maple (Michigan, Wisconsin, and Minnesota), northern pin oak (northern Lower Peninsula), and hickory (Menominee and Dickinson Counties) are experiencing recently reported declines. Drought is a suspected factor in each decline. Repeated defoliations by forest tent caterpillar, gypsy moth, and large aspen tortrix have decreased the vigor of some aspen. With this decreased vigor, these aspen are affected by secondary pests such as Armillaria root rot, bronze poplar borer, aspen leafblotch miner, and Septoria leaf spot. Mortality of the larger aspen is often associated with *Hypoxylon* canker. *Diplodia scrobiculata, Therrya* spp., and possibly lichen are linked to the white pine decline. Smaller white pine trees are most severely affected. Poor soil conditions and weather are associated with maple decline. Forest floor disturbance by exotic earthworms is correlated with crown dieback in maple. Oak mortality and decline has resulted from sandy soils, drought, late-spring frosts, two-lined chestnut borer, and over-mature northern pin oak. Hickory wilt, a combination of bark beetles and fungus, is associated with hickory decline.

What this means

Michigan's forest land is host to a variety of native and nonnative insects and diseases. While varying in severity, these organisms affect forest resources across the State. Adverse environmental conditions interact with these pathogens in various ways with weather playing a major role. In many cases, trees on poorer soils are at greater risk.

Recommended management practices can mitigate some adverse effects. For example, Pugh (2011) analyzed a Kirtland's warbler management area where jack pine stands are maintained at younger ages to benefit nesting. Net growth was more than double and mortality about half compared to estimates observed for the remaining area of jack pine in the State. It is recommended that harvests occur before jack pine stands reach maturity.

Nonnative species such as EAB and BBD are playing a larger role in affecting Michigan's forest health. Because of the lack of natural enemies and specific plant defense mechanisms, these pests cause considerable mortality that alters forest structure and composition. Federal and state agencies and universities are working together to combat and monitor these pests. The U.S. Forest Service and Michigan State University have created an Internet site to host the latest information on EAB (www.emeraldashborer.info). A number of groups, including the U.S. Forest Service, MIDNR, Michigan Technological University, and Michigan State University, monitor BBD and propagate disease-resistant American beech.

The State's forests also face potential serious risk from the introduction of the Asian longhorned beetle (many genera of hosts, including maple, birch, aspen, and ash), sudden oak death or ramorum blight, balsam woolly adelgid, and thousand cankers disease of walnut. Movement of firewood can exacerbate the spread of these pests so there is a general advisory against moving any firewood.

Like many parts of the Nation (Smith et al. 2009), Michigan has experienced an increase in tree mortality (see Annual Mortality). Continued monitoring will provide essential information on emerging issues and trends. Even with the recent increase in mortality for some tree species, the rate of mortality to current volume at the State level is only 1.1 percent of volume on forest land. Within forest health circles, a mortality rate less than 3 percent is generally viewed as an acceptable rate of background morality.

Regeneration Status

Background

The composition and abundance of tree seedlings drives the sustainability of forest ecosystems in the early years of stand development and sets the stage for future composition and structure, and hence, the viability of timber and ecosystem services. Establishing and retaining preferred high canopy species following stand-replacement disturbances, such as final harvest or catastrophic mortality, are the key to sustaining forest values for the long-term future.

Forest systems of Michigan face a number of regeneration stressors such as invasive plants, insects, diseases, changing climate, and herbivory. As stands mature and undergo disturbance, it is imperative to know the condition of the seedling component because regeneration data are important for understanding and projecting the future forest character of Michigan's forests.

Early successional young forest habitat provides unique plant biota, wildlife habitat, and landscape heterogeneity (Greenberg et al. 2011). Some prime examples of wildlife that depend on young forest habitat are golden-winged warbler (*Vermivora chrysoptera*), American woodcock (*Scolopax minor*), and cottontail rabbit (*Sylvilagus floridanus*) (Gilbart 2012). The vitality of Michigan's young forests depends directly on the abundance, composition, and condition of tree regeneration.

To fill the need for more detailed information on regeneration, the Northern Research Station, FIA program added measurement protocols collected on a subset of sample plots measured during the growing season (McWilliams et al. 2015). The results in this report are based on measurements of 345 sample plots measured from 2012 to 2014 as part of the Phase 2+ inventory (P2+; see Gormanson et al. 2017). The procedures measure all established tree seedlings less than 1 inch d.b.h. by length (height) class and include a browse impact assessment for the area surrounding the sample location. The regeneration indicator (RI) data improve FIA's ability to evaluate this important aspect of forest health and sustainability.

What we found

As Michigan's forest stands continue to age, young forests (0 to 20 years old) are becoming less common. Since 1980, the area of young forest decreased from about one-quarter of Michigan's forest land to 10 percent. Forest-type group definitions have changed since 1980 but it is still evident that the area of young forest declined for all major forest-type groups in Michigan. The maple/beech/birch group had the most drastic change with nearly a fivefold decrease in the area of young forest that now makes up only 4 percent of the forest land in the group. Young oak-hickory and spruce-fir forests each account for just 6 percent of their total acreage.

The browse impact assessment results show that most of the plots had medium (59 percent) or low (37 percent) browse impact on understory plants (Fig. 37). Only 4 percent were found to have high browse levels and very high browse impact conditions were not encountered. Examination of browse impact across the State reveals that most of the samples with high levels of browse impact were found in the eastern Upper Peninsula.

The total number of seedlings is estimated at 193.0 billion, or a statewide average of 9,269 seedlings/acre. Sixty-three percent of the seedlings are less than 1 foot tall, 32 percent are 1.0 to 4.9 feet, and 5 percent are 5.0 feet and taller (Fig. 38). Higher levels of seedling abundance were most evident in the Upper Peninsula (Fig. 39).

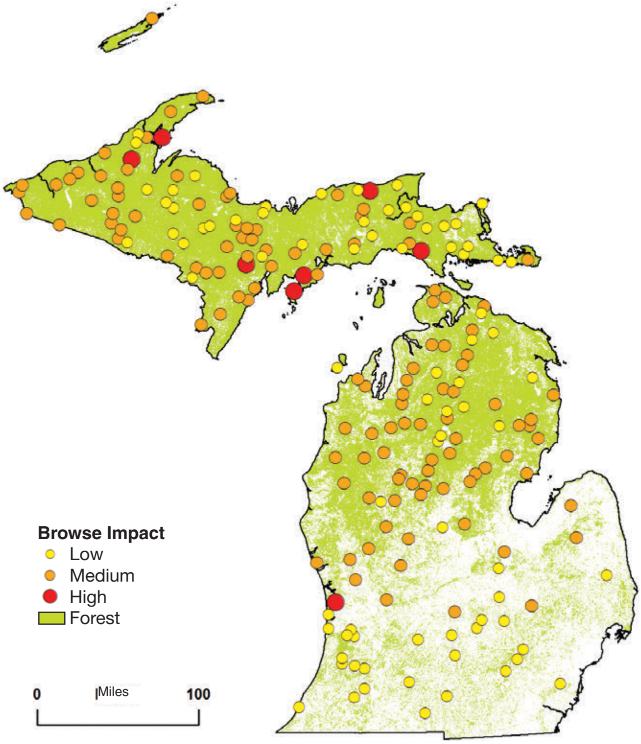

Figure 37.—Browse impact as observed on P2+ plots, Michigan, 2012-2014 The low and very low browse impact classes are combined. Plot locations are approximate. For data source and description of this map and all maps, see appendix 2.

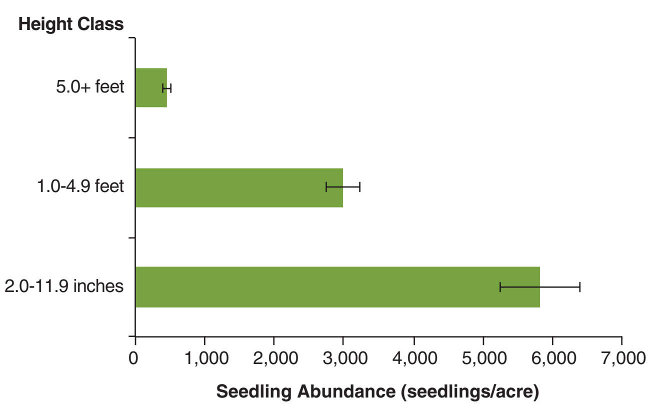

Figure 38.—Average number of seedlings per acre on forest land by seedling height class, Michigan, 2012-2014; error bars represent 68 percent confidence interval around estimate.

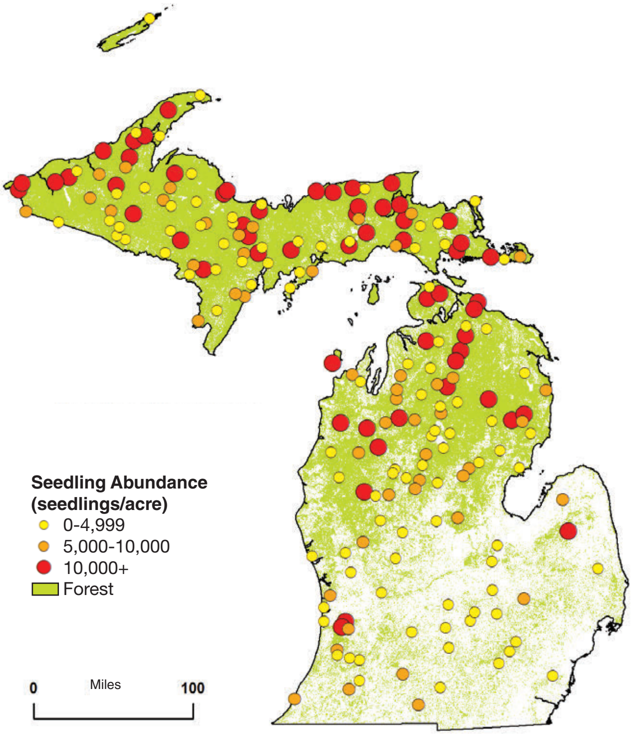

Figure 39.—Seedling abundance on P2+ plots on forest land, Michigan, 2012-2014. Plot locations are approximate. For data source and description of this map, see appendix 2.

Fifty-six species or species groups were encountered on the RI plots. Maple was the most prevalent genera with 57 percent of the seedlings (Fig. 40). Sugar and red maple were the most common species at 31 and 23 percent, respectively. American beech, balsam fir, and white ash each had 5 percent; all other species or species groups had less than 5 percent of the population. Noncommercial and low-canopy species, such as striped maple and chokecherry, were relatively minor components with the exception of serviceberry spp. that made up 3 percent of the total.

Comparing species abundance (using the percentage of total number of trees by height and diameter class) highlights potential pathways for future canopy dominants. Figure 41 depicts results for select species and species groups of seedlings, saplings, and dominant/co-dominant growing stock or "adult" trees (at least 5 inches d.b.h.). Prospective "gainers" are those species with relatively high percentages of stems in the pool of seedlings and saplings compared to adults. Sugar maple, red maple, and ash are the most apparent gainers (Fig. 41). Expectations for ash should be tempered with information on the ill effects of EAB. Prospective "losers" in the process of developing future canopy dominants are species with lower percentages in the regeneration pool than the adult pool. Potential losers are the oaks and northern white-cedar (Fig. 41). Cottonwood/aspen and balsam fir appear to be potential losers, but both have an abundance of saplings compared to seedlings. The distribution of stem abundance by size class is particularly out of balance for the oaks, where seedlings, saplings, and young adults are rare compared to older adults.

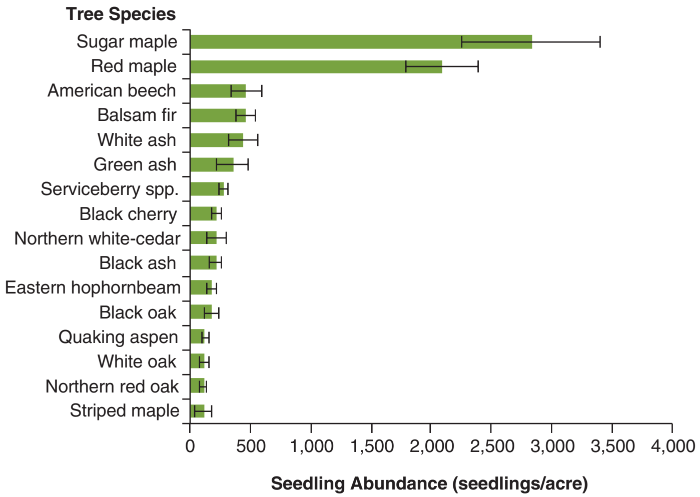

Figure 40.—Average seedling abundance per acre for selected species with at least 1 percent of the total number of seedlings, Michigan, 2012-2014; error bars represent 68 percent confidence interval around estimate.

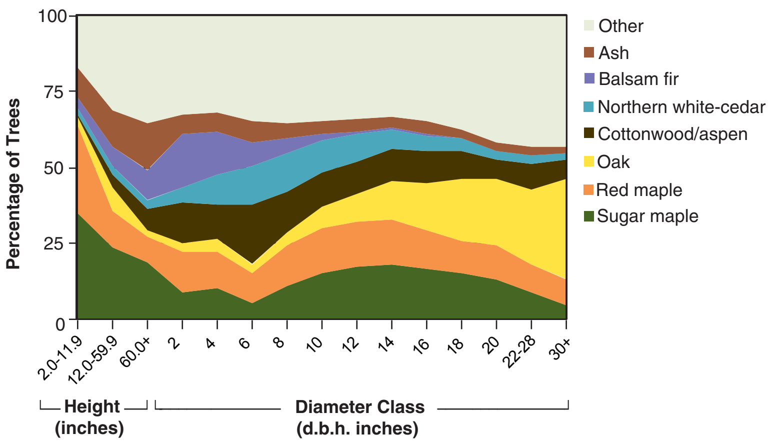

Figure 41.—Percentage of total number of seedlings, saplings, and adult trees on forest land for select species and species groups by size, Michigan. Seedling estimates are for 2012-2014. Sapling and tree estimates are for the 2014 inventory.

What this means

The inventory and subsequent management of seedlings and saplings can be powerful tools to address a variety of forest health risks facing Michigan's forests. Deer browse is a major factor affecting regeneration and related resources in the eastern United States (Russell et al. 2001, White 2012). In Michigan, nearly two-thirds of the RI samples measured had at least medium browse impact. This is an indication that in some areas browsing by deer is influencing composition of the regeneration component. It would be expected that local areas with high deer populations will have limited reproduction of palatable tree species. Impacts of deer browsing are especially problematic when occurring in combination with habitat fragmentation and incursion by invasive plants that are more common in populated areas of the State (Augustine and deCalesta 2003).

Maple/beech/birch group, dominated by sugar maple and red maple species, is Michigan's most common forest-type group with 30 percent of the forest land. The relative dearth of young maple/beech/birch stands might suggest that at some point, management aimed at establishing healthy young stands will be needed. However, sugar maple is very tolerant of shade and is often gradually released from competition to encourage favorable crown form and limit epicormic sprouting. Red maple is also shade tolerant and responds well to gradual release of competition. Sugar maple is one of the most important commercial species and uneven-age management will likely remain the most common and successful tool ensuring its proper stewardship. Despite the low acreage in young maple/beech/birch stands, the abundance of juvenile sugar and red maple seedlings bodes well for the future of the maple/beech/birch forest-type group.

Oak/hickory is the second most common group with 17 percent of Michigan's forest land. Oak regeneration is a common problem in the eastern United States (Holt and Fischer 1979). These results showing low numbers of oak seedlings, saplings, and young adults make the future of oak/hickory forests uncertain. The long-term future of oak-dominated forests will depend on management strategies that establish oak seedlings and foster development of saplings and adults using stand tending prescriptions that forestall development of more shade tolerant species such as sugar and red maple (Abrams 1992, Dey 2014).

Aspen/birch ranks as the third most common group (15 percent of forest land). Although the relatively low abundance of aspen seedlings implies a loss of stature in the future, an abundance of saplings and young adults combined with continued management should maintain aspen. Aspen management typically involves shorter rotations and treatments that remove the dominant overstory to allow development of young stems. Aspen accounts for the greatest percentage of industrial roundwood production by species (see Timber Product Output).

The spruce/fir group is ranked fourth with 12 percent of the State's forest land. The group is comprised of forest types with relatively few species making up the dominant canopy, e.g., the balsam fir and black spruce forest types. Management of balsam fir following overstory removal will need to consider regenerating adequate numbers of seedlings for retention as saplings as indicated by the lower stocking of seedlings revealed in these results. Black and white spruce bear careful monitoring as the current sample is not statistically adequate for making reasonable conclusions on the future status of the group. These issues are important because of the prominent role of spruce/fir in providing timber and other resources.

It is difficult to draw firm conclusions for the other forest-type groups because of the statistical uncertainty of the estimates. It is evident that the future status of elm/ash/cottonwood will depend on an abundant population of ash seedlings whose future will be determined by impacts of EAB. Results for the white/red/jack pine group are also subject to high sampling errors. More information is needed to address this important group and its constituent forest types.

Eventually, most forest stands will experience either anthropogenic or natural stand replacement events and require establishment of new young forest. Clearly, forest regeneration will be the key to successful formation of healthy young forests. Management options for regeneration of palatable species will also be driven by the amount of browse present. Tending of young stands to control composition and stocking levels is also an important factor (Johnson et al. 2002, Smith et al. 1997).

The results presented here reflect approximately 43 percent of measurements that will eventually comprise the first full baseline dataset for the RI. Barring any extension of the inventory cycle length, the next 5-year inventory report for Michigan will coincide with the completion of the full baseline dataset. This will facilitate more detailed analyses including species-specific details, and improve the level of statistical confidence in the estimates. The dataset will also facilitate research to evaluate plot-level regeneration adequacy for the major forest-type groups and a more complete understanding of future trends in composition, structure, and health of Michigan's forests.

Tree Crown Health and Damage

Background

The status of tree crowns as characterized by crown dieback can indicate forest health. Crown dieback (for live trees at least 5 inches d.b.h.) is defined as recent mortality of branches with fine twigs and reflects the severity of recent stresses on a tree. Like mortality, dieback is a natural part of forest stand development. A crown is labeled 'poor' if crown dieback is greater than 20 percent. This threshold is based on findings by Steinman (2000) who associated crown ratings with tree mortality. Additionally, Morin et al. (2015) identified dieback as the most effective variable for predicting tree survival.

As part of the Phase 3 (P3) and P2+ inventories, detailed crown information, including crown dieback, has been collected since 2000 with the exception of 2011 when collection was temporarily suspended (Gormanson et al. 2017). Findings reported here are based on information from 211 plots and 5,647 trees for the 2009 inventory and 255 plots and 6,843 trees for the 2014 inventory.

Damage on live trees (at least 5 inches d.b.h.) can also indicate forest health and is a natural part of forest-stand development. Damage was assessed on forest land for the 2009 and 2014 inventories (7,516 and 6,635 plots, respectively). A damage agent is recorded when it is expected to kill or reduce the growth of the tree in the near term or negatively affect marketable products from the tree, or both. The following damage agents can be recorded: insect damage, cankers, decay, fire, animal damage, weather, and logging damage. If there are more than three agents, only the three most important ones are recorded (agents threatening survival are more important than agents that reduce wood quality).

What we found

The incidence of poor crowns is common but there is no discernable spatial pattern (Fig. 42). Ash species have the highest proportion of basal area with poor crowns (21 percent) followed by American beech (11 percent) (Fig. 43); that proportion has increased substantially for both species since 2009. The mean dieback for ash and American beech in the 2014 inventory is 15 and 6 percent, respectively. Proportional basal area in poor crowns is below 10 percent for the remaining selected species. The remaining species have mean dieback of 4 percent or less, except for yellow birch at 6 percent. It is important to note that these data are based on a limited sample size.

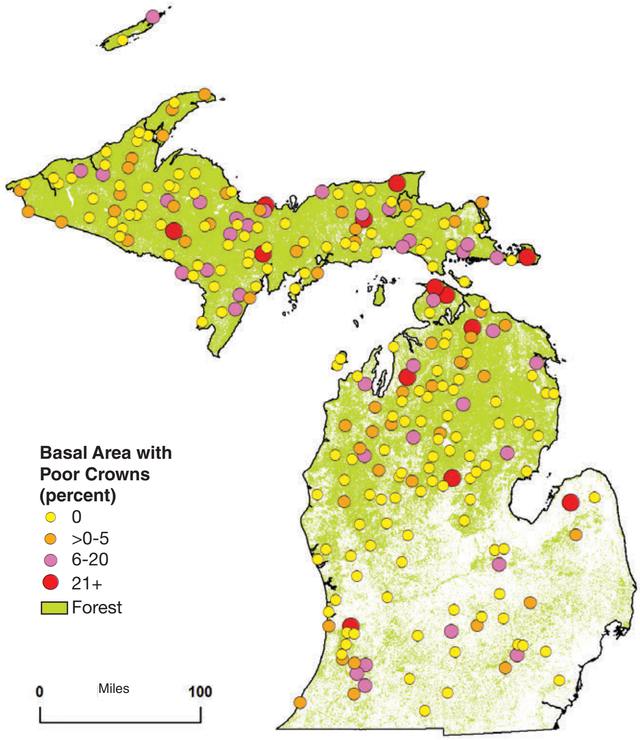

Figure 42.—Percentage of basal area with poor crowns in trees at least 5 inches d.b.h., Michigan, 2014. Plot locations are approximate. For data source and description of this map, see appendix 2.

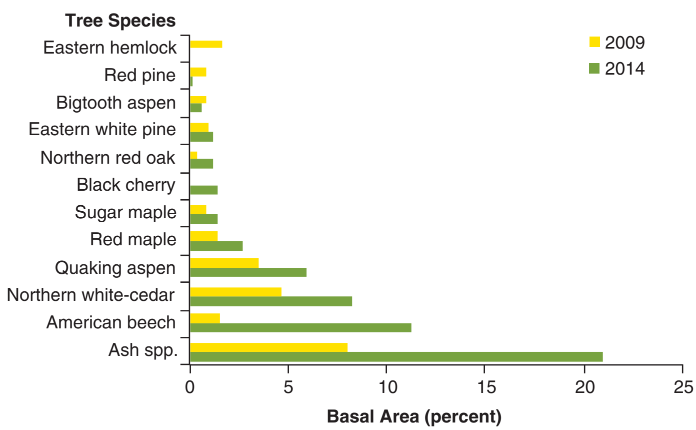

Figure 43.—Percentage of basal area with poor crowns for live trees (select species) at least 5 inches d.b.h., Michigan, 2009 and 2014.

The proportion of trees that die increases with increasing crown dieback (Fig. 44). Forty percent of trees with crown dieback above 20 percent during the 2009 inventory were dead when visited again during the 2014 inventory.

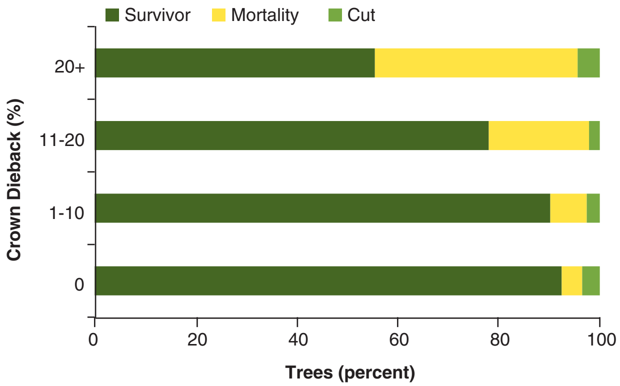

Figure 44.—Percentage of remeasured trees at least 5 inches d.b.h. by crown dieback and survivorship, Michigan, 2014.

Damage was recorded on approximately 23 percent of the sampled trees in Michigan, but the frequency of damage varies among species. The most frequent damage on all species was decay (13 percent of trees), but it ranged from 5 percent or less on pine, spruce, and fir up to 36 percent on American beech. Insect damage was present on 45, 21, and 13 percent, respectively, on eastern white pine, ash, and sugar maple. Cankers were present on 22 and 8 percent of American beech and quaking aspen trees, respectively. The occurrence of all other injury types was very low (Fig. 45). The frequency of damage for most species has remained stable between 2009 and 2014. The exceptions to this generality are the substantial increases of insect damage on ash (19 percent) and eastern white pine (32 percent), and cankers on American beech (20 percent).

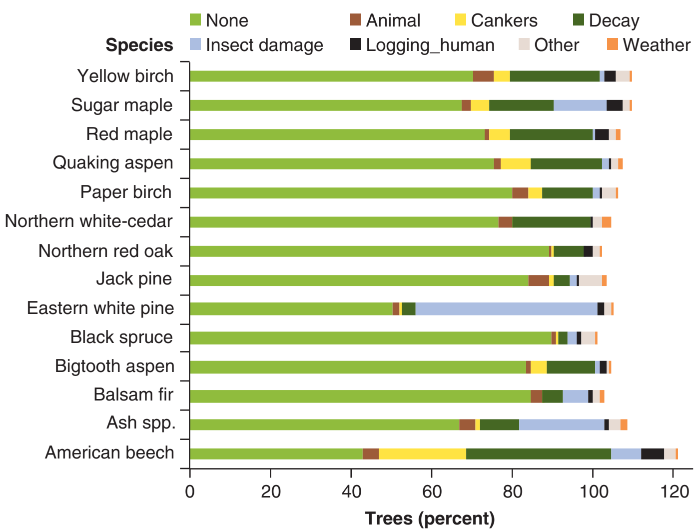

Figure 45.—Percentage of live trees at least 5 inches d.b.h. with observed damage, Michigan, 2014. Up to three damage types could be recorded per tree.

What this means

No major health problems are indicated in the crown data for most important species, but ash and American beech have high and increasing occurrences of poor crown health. The unhealthy crowns in ash indicate impending mortality related to EAB. This is further illustrated by the high percentage of ash trees with insect damage. In American beech, BBD causes poor crown health and high occurrence of cankers.

The native white pine weevil causes deformed stems and contributes to the high incidence of white pine damage. Although the weevil damage does not typically kill trees, the form and quality of saw logs are impacted as evidenced by the increasing proportion of damaged trees that fall into grades 3 and below (higher tree grade numbers indicate lower quality) (Fig. 46). The noticeable increase of insect damage on eastern white pine since 2009 is partially due to a change in methods during the 2014 inventory. This change allowed for easier identification of white pine weevil damage. Insect damage on white pine will be monitored closely to identify any substantial changes in the upcoming inventories.

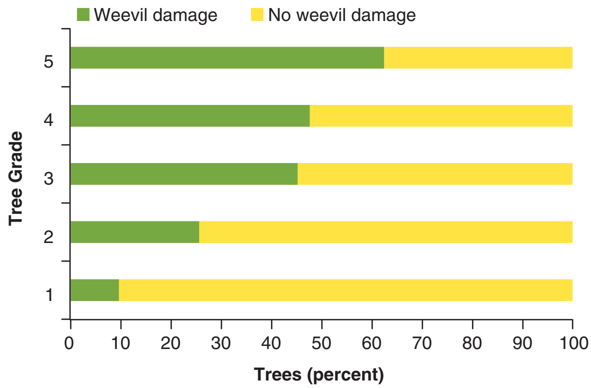

Figure 46.—Percentage of sawtimber-size white pine trees by tree grade and white pine weevil damage, Michigan, 2014.

The incidence of cankers on quaking aspen is likely due to Hypoxylon canker, which is one of the most imposing killing diseases of aspen in eastern North America (Anderson et al. 1997).

The health of maple species, eastern hemlock, and eastern white pine are at risk due to likely future invasions by Asian longhorned beetle, hemlock woolly adelgid, and Sirex wood wasp. By monitoring crown dieback and damage, we may be able to identify health issues such as these before they become unmanageable.

Invasive Plants

Background

Invasive plant species (IPS) are both native and nonnative species that can cause negative ecological effects. These species can quickly invade forests changing water, light, and nutrient availability (Kuebbing et al. 2014). IPS can form dense monocultures, which not only reduce regeneration but also impact wildlife quality through altering forest structure and forage availability (Pimentel et al. 2005). Aside from the effects invasive species cause in forested environments, they can also impact agricultural systems (Kurtz 2013). An example is common barberry, an alternate host for wheat stem rust (*Puccinia graminis*), which can cause the complete loss of grain fields. Common buckthorn is another troublesome IPS as it is an alternate host for the soybean aphid (*Aphis glycines*). While there are some beneficial uses for these invaders (e.g., culinary, medicinal, and soil contaminant extraction) (Kurtz 2013), the negative effects are worrisome. Each year the inspection, management, and mitigation of IPS costs billions of dollars (Kurtz 2013, Pimentel et al. 2005).

To aid in monitoring these species, FIA assessed the presence of 40 IPS (39 species and one undifferentiated genus[3]) on 623 forested plots in Michigan for the 2014 inventory (P2 invasive plots from the P2+ inventory and a subset of the P2 inventory; see "Statistics and Quality Assurance"). To maintain regional consistency, the species list is not customized for Michigan but represents native and nonnative species of regional concern.

What we found

Of the 40 invasives monitored (appendix 7), 25 were observed (Table 7). Canada thistle (Fig. 47) was the most commonly observed species and was found throughout the state. Autumn olive was the second most commonly recorded IPS and was primarily observed in the Lower Peninsula. Figure 48 shows plots that had one (17 percent), two to three (11 percent), four to six (4 percent), seven to nine (1 percent), or zero (67 percent) of the monitored species. The Lower Peninsula has the greatest number of IPS per plot.

[3] Hereafter the IPS and one undifferentiated genus (nonnative bush honeysuckles, *Lonicera* spp.) are referred to as "invasive species," "invasive plants," "invasives," or "IPS."

Table 7.—Invasive plant species recorded on P2 Invasive plots, Michigan, 2014

Species	Number of plots	Percentage of plots
Canada thistle	*65*	*10.4*
Autumn olive	55	8.8
Multiflora rose	54	8.7
Honeysuckle (nonnative bush)	51	8.2
Spotted knapweed	34	5.5
Reed canarygrass	31	5.0
Garlic mustard	28	4.5
Common buckthorn	17	2.7
Bull thistle	16	2.6
Glossy buckthorn	14	2.2
Japanese barberry	10	1.6
Common barberry	9	1.4
Black locust	7	1.1
Oriental bittersweet	7	1.1
European privet	6	1.0
Creeping jenny	5	0.8
Dames rocket	5	0.8
Common reed	4	0.6
Siberian elm	4	0.6
Japanese honeysuckle	2	0.3
Russian olive	2	0.3
Leafy spurge	2	0.3
Tree-of-heaven	1	0.2
Giant knotweed	1	0.2
Norway maple	1	0.2

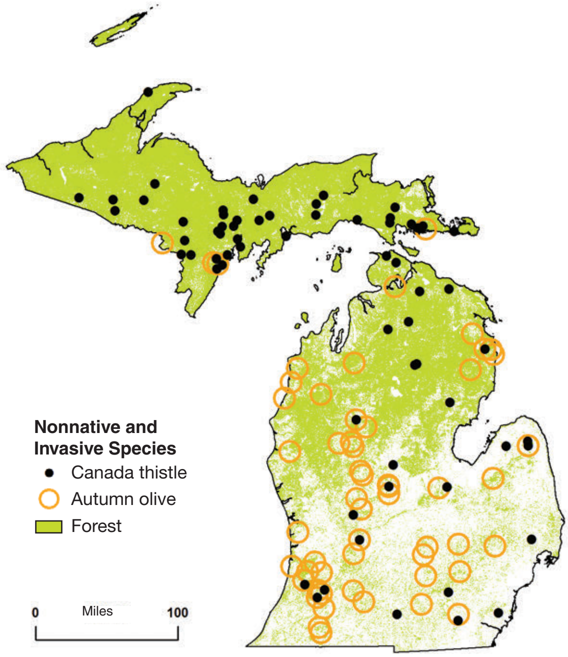

Figure 47.—Distribution of P2 invasive plots where Canada thistle and autumn olive were observed, Michigan, 2014. Plot locations are approximate. For data source and description of this map, see appendix 2.

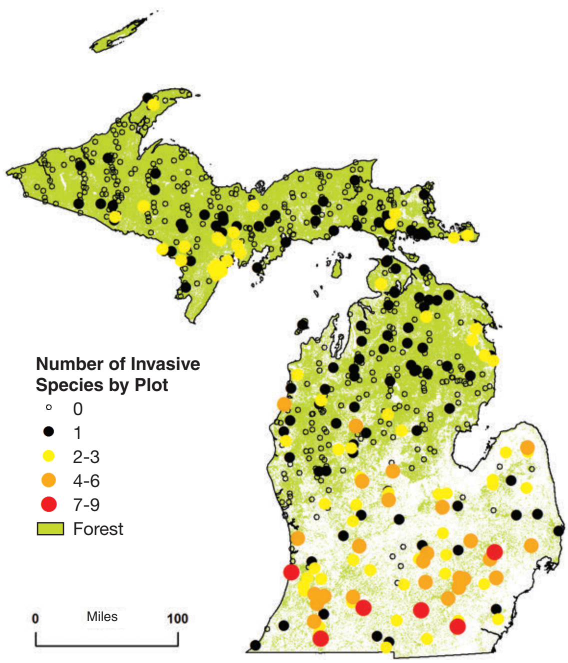

Figure 48.—Number of invasive plant species observed on P2 invasive plots, Michigan, 2014. Plot locations are approximate. For data source and description of this map, see appendix 2.

The 2014 inventory recorded fewer IPS than the 2009 inventory (681 forested plots sampled) but the 2014 sampling intensity was lower. Twenty-nine species were reported for 2009 (28 species plus nonnative bush honeysuckles) and multiflora rose was the most commonly observed invasive plant species, occurring on 10.6 percent of plots (Pugh et al. 2012). Purple loosestrife, Nepalese browntop, European cranberrybush, and Japanese knotweed were observed in 2009 but not in 2014. Each of these four species was only found on one plot in 2009, with the exception of purple loosestrife, which was found on two plots.

Michigan's forests had a lower percentage of plots invaded (33.2 percent) than neighboring Indiana (90.7 percent) (Gormanson et al. 2016) and Ohio (93.2 percent) (Widmann et al. 2014). However, the number of IPS observed was similar across these states with 25 species in Michigan, 25 in Indiana, and 28 in Ohio.

What this means

Invasive species are a concern throughout the Midwest because many IPS are effective competitors and able to change forested ecosystems by displacing native species and altering forage. Furthermore, IPS can cause negative economic impacts by reducing timber yield and aesthetic beauty. Several characteristics contribute to their success: prolific seed production, rapid growth, vegetative propagation, and endurance of harsh conditions. Many factors contribute to forest invasion, such as ungulates, development, forest fragmentation, and timber harvesting, however, some can establish with little to no disturbance. Additional investigation may reveal correlations between IPS and influential site and regional features as well as IPS factors associated with forest dynamics. Even with limited samples, continual monitoring and reporting of IPS informs managers and the general public of their occurrence and spread.

Urbanization and Fragmentation

Background

The expansion of urban lands that accompanies human population growth often results in the fragmentation and urbanization of remaining natural habitat (Wilcox and Murphy 1985). Continuing fragmentation, parcelization, and urbanization can be barriers to stewardship if they result in forest tracts that are too small or too isolated for effective management (Shifley and Moser 2016). Forest fragmentation can increase edge conditions which can change micro-climate conditions and ecosystem processes limiting the ability of tree species to move in response to climate change (Iverson and Prasad 1998). An intact functioning forest also is critical in protecting both the quantity and quality of surface and groundwater resources (McMahon and Cuffney 2000, Riva-Murray et al. 2010).

Forest fragmentation and habitat loss diminish biodiversity and are recognized as a major threat to animal populations worldwide (Honnay et al. 2005, Rosenberg et al. 1999), particularly for species that require interior forest conditions for all or part of their life cycle (Donovan and Lamberson 2001), are wide-ranging, slow-moving, and/or slow reproducing (Forman et al. 2003, Charry and McCollough 2007). Changes in the size of remaining forest patches, in their level of connectivity to other large patches, in the amount of general forest cover surrounding each patch, and in the amount of forest-nonforest edge, directly affect the amount and quality of interior forest. The same factors may also affect the ease with which nonnative, invasive, or generalist species can gain a foothold and spread throughout the landscape.

Landscape pattern metrics help quantify these characteristics of fragmentation. The 2011 National Land Cover Dataset (2011 NLCD) (Jin et al. 2013) shows land cover varying considerably across Michigan, ranging from the heavily forested Upper Peninsula (84 percent) and northern Lower Peninsula (61 percent) to the predominantly agricultural (52 percent) and urban (18 percent) southern Lower Peninsula.

We adapted a spatial integrity index (SII) developed by Kapos et al. (2002) for the Global Forest Resources Assessment that integrates three important facets of fragmentation affecting some aspect of forest ecosystem functioning (patch size, local forest density, and patch connectivity to core forest areas) to create a single metric where 1 indicates a highly fragmented area while 10 represents the highest forest spatial integrity.

Metric values are sensitive to the resolution of source land cover data (Moody and Woodcock 1995) and acceptably low misclassification rates in the data can substantially magnify errors in the metrics (Langford et al. 2006, Shao and Wu 2008). Furthermore, important forest ecosystem processes operate at different scales. Consequently, we calculated spatial integrity using two reliable and widely available data sets of differing scale—2006 NLCD at 30 m (Fry et al. 2011) and 2009 FIA forest cover at 250 m (Wilson et al. 2012). Both scales fall within the 10 to 1,000 km^2 range at which pattern process linkages are often of greatest management interest (Forman and Godron 1986).

In the SII calculation, core forest is defined by a minimum patch size and minimum local forest density within a defined local neighborhood (Table 8). A forest fragment (unconnected area) is defined by a maximum patch size, maximum local forest density, and minimum distance to core forest. The spatial integrity of remaining forest land is scaled between fragmented and core forests (low, medium, and high integrity). At the 250 m scale, core forest requires a minimum forest patch size greater than 1,544 acres (2.41 miles^2) and patches less than 30 acres (0.05 miles^2) are fragments. At the 30 m scale, the analogous minimum and maximum areas are 22 and 2.5 acres for core and fragmented forest, respectively. Local forest density is calculated within a radius of 0.78 miles (1.91 miles^2) for the 250 m scale and within a radius of 0.09 miles (0.03 miles^2) for the 30 m scale. Core forest requires a minimum 90 percent forest density within each local neighborhood at each scale.[4] Fragments can have a maximum 10 percent local forest density. These scales capture a relatively broad range of definitions for core forest and spatial integrity that should bracket the scales appropriate for understanding impacts on a wide range of wildlife species and ecosystem processes affected by forest fragmentation.

Table 8.—Spatial integrity index parameters by 30 m (2006 NLCD) and 250 m (2009 FIA forest cover) scales, Michigan

Definition	250 m scale	30 m scale
Core:		
Patch size (acres)	>1,544	>22
Local forest density (%):	≥90	≥90
Neighborhood radius (miles)	0.78	0.09
Fragment:		
Patch size (acres)	<30	<2.5
Local forest density (%):	≤10	≤10
Neighborhood radius (miles)	0.78	0.09
Distance to core (miles)	>4.2	>0.5

Unlike its surrounding states, the human population of Michigan decreased by 0.7 percent between 2000 and 2010, to 9.88 million. However, the number of housing units increased by 7.1 percent during the same period (U.S. Census Bureau 2015a). Increases in housing units have been generally outpacing increases in population throughout the country. In recent decades, this housing growth has occurred not only in increasing suburban rings around urban areas but also in rural areas. Lepczyk et al. (2007), Theobald (2005), and Hammer et al. (2004) observed that among the areas

[4] Riemann, R. 2014. Adaptation of a spatial integrity index to 30 m and 250 m scales and its application across the northeastern United States. Unpublished.

facing particularly rapid increases in housing density, currently and into the future, are amenity-rich rural areas around lakes and other forest recreation areas. The 13 percent increase in the number of reported second homes from 2000 to 2010 (U.S. Census Bureau 2015a) could be a partial reflection of this trend in Michigan. This can put additional pressure on forested areas even above the general increases in population density and housing density.

Since SII does not consider underlying housing density or proximity to roads, it does not represent completely intact forest conditions. The wildland-urban interface (WUI) is the zone where human development meets or intermingles with undeveloped wildland vegetation (Radeloff et al. 2005). It is associated with a variety of human-environment conflicts. Radeloff et al. (2005) have defined this area by housing density ("intermix" areas that require a minimum of 16 houses/mile^2), proximity to developed areas ("interface" areas), and percentage of vegetation coverage (minimum 50 percent). We intersected WUI intermix areas (based on 2010 U.S. Census Bureau) with forest land from the 2011 NLCD to examine changes in forest land area by WUI housing density. In addition, the coincidence of SII core forest (based on forest canopy) and WUI intermix was identified.

Neither of the previous indices capture the full impact of roads on forest land. Roads can have a variety of effects: direct hydrological, chemical, and sediment impacts; anthropogenic impacts; invasive species; habitat fragmentation; and wildlife mortality. Actual impacts will vary depending on road width, use, construction, level of maintenance, and hydrologic and wildlife accommodations (e.g., Charry and McCollough 2007, Forman et al. 2003). We identified the amount of forest land (2001 NLCD) (Homer et al. 2007) within 650 and 1,310 feet from a road (2000 TIGER/Line files) (U.S. Census Bureau 2000). In general, when more than 60 percent of a region is within 1,310 feet of a road, cumulative ecological impacts from roads should be an important consideration (Riitters and Wickham 2003).

What we found

SII at the 250 m scale shows 69 percent of Michigan's forest land as core, 15 percent with high spatial integrity, 4 percent with medium integrity, 1 percent with low integrity, and 12 percent is in unconnected fragments (Table 9). At the 30 m scale, 66 percent is core forest, 19 percent has high integrity, 4 percent has medium or low integrity, and 10 percent is forest fragments. Forest connectivity is highest in the Upper Peninsula and lowest in the southern Lower Peninsula. Large areas of relatively continuous forest stand out in Figure 49, which shows spatial distribution of forest land by SII classes at the 250 m scale. In these areas, the larger patch size threshold and lower resolution of the 250 m scale SII results in a higher percentage of core forest compared to the smaller threshold and higher resolution of the 30 m scale SII (nonforest gaps are more influential). In highly fragmented areas such as the Lower Peninsula, the lower threshold of the 30 m scale SII classifies more patch area as core (4 and 29 percent as core for 250 m and 30 m scale, respectively). Figure 50 compares SII classes by scale for an area north of Grand Rapids. The SII is depicting tree cover only and may not incorporate the presence of local development associated with or underlying this tree cover. Addressing this requires housing density information.

Table 9.—Spatial integrity index (SII) by region, scale, and with and without wildland-urban interface (WUI) intermix as core forest, Michigan

Region	Forest by 30 m SII class					
	Fragment	Low SII	Medium SII	High SII	Core	Core without WUI
	---------- percent ----------					
Eastern Upper Peninsula	2	1	4	15	79	74
Western Upper Peninsula	1	0	1	9	89	85
Northern Lower Peninsula	8	0	5	24	63	49
Southern Lower Peninsula	35	1	8	26	29	16
Statewide	10	0	4	19	66	56
Statewide without WUI	10	1	5	28	56	not applicable

Region	Forest by 250 m SII class					
	Fragment	Low SII	Medium SII	High SII	Core	Core without WUI
	---------- percent ----------					
Eastern Upper Peninsula	0	0	1	12	87	82
Western Upper Peninsula	0	0	0	5	95	89
Northern Lower Peninsula	3	1	6	24	66	53
Southern Lower Peninsula	75	2	9	10	4	3
Statewide	12	1	4	15	69	61
Statewide without WUI	12	1	4	21	61	not applicable

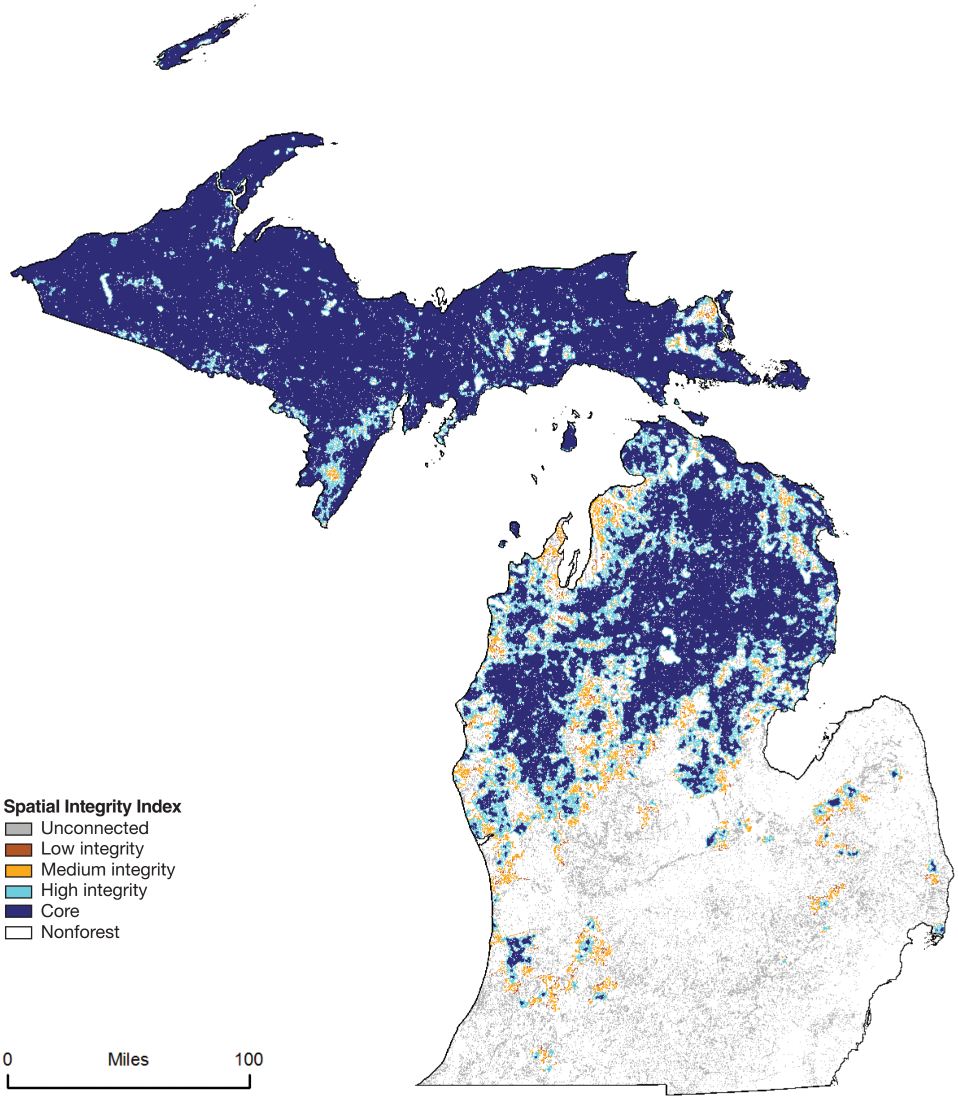

Figure 49.—Spatial integrity index of forest land at the 250 m scale, Michigan. For data source and description of this map, see appendix 2.

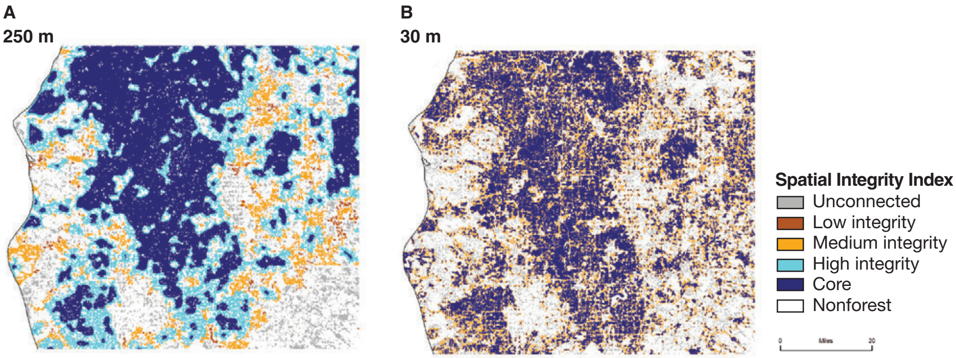

Figure 50.—Spatial integrity index of forest land at the 250 m scale (A) and 30 m scale (B) in a region north of Grand Rapids, Michigan. For data source and description of this map, see appendix 2.

WUI area has been steadily increasing with increasing housing density. In 1990, 17 percent of Michigan's forest land was in low (16 to 128 houses/mile^2) and medium density (129 to 1,920 houses/mile^2) WUI. This increased to 20 percent in 2000 and 22 percent in 2010. In 2010, the northern Lower Peninsula and southern Lower Peninsula had 30 and 40 percent of forest in WUI areas, respectively (Table 10 and Fig. 51). In contrast, the western and eastern portions of the Upper Peninsula had 7 and 8 percent of forest in WUI areas, respectively. Integrating SII results at the 250 m scale with WUI, core forest drops from 69 to 61 percent (Table 9). At the 30 m scale, core forest drops from 66 to 56 percent. This effect is greatest in the Lower Peninsula. Figure 52 compares SII with and without WUI in a region north of Grand Rapids.

Table 10.—Distribution of forest land by region and fragmentation metric, Michigan

Region	Forest[a]	Forest in WUI intermix[b]	Forest within 650 feet of road[c]
	----------	*percent*	----------
Eastern Upper Peninsula	79	8	31
Western Upper Peninsula	88	7	31
Northern Lower Peninsula	61	30	46
Southern Lower Peninsula	27	40	43
Statewide	54	22	39

[a] Forest from NLCD 2011 (Jin et al. 2013)

[b] Wildland-urban interface (WUI) intermix (based on 2010 U.S. Census Bureau)

[c] Roads (Census 2000 TIGER/Line files from U.S. Census Bureau 2000)

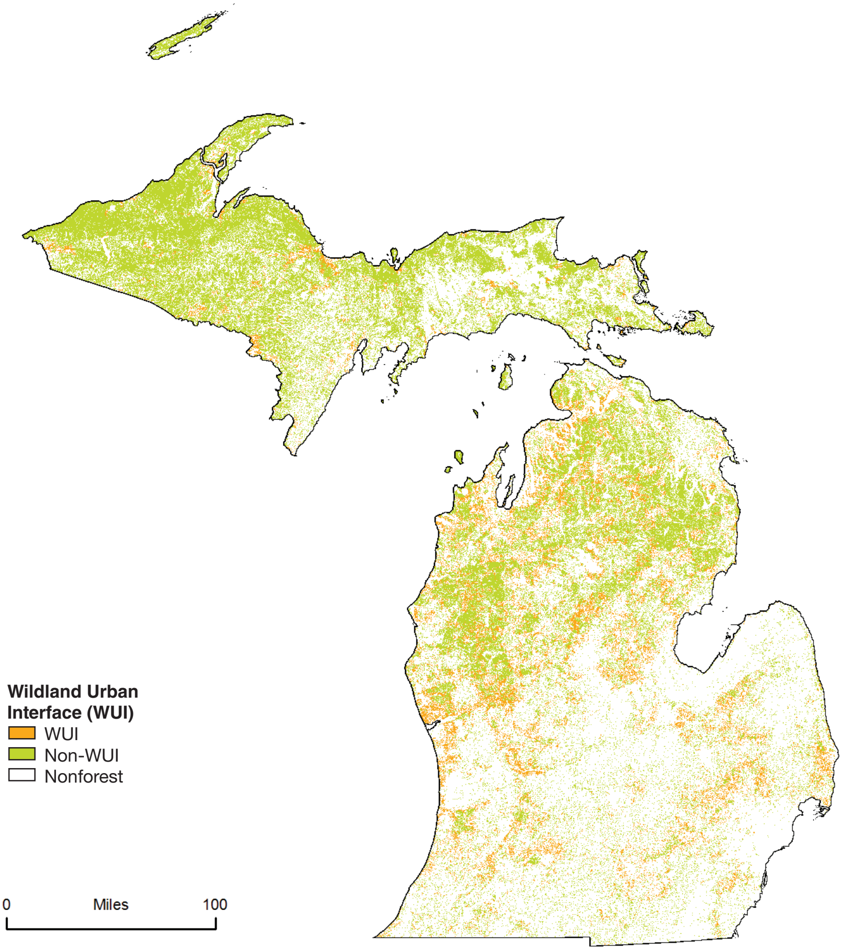

Figure 51.—Wildland-urban interface intermix status, Michigan. For data source and description of this map, see appendix 2.

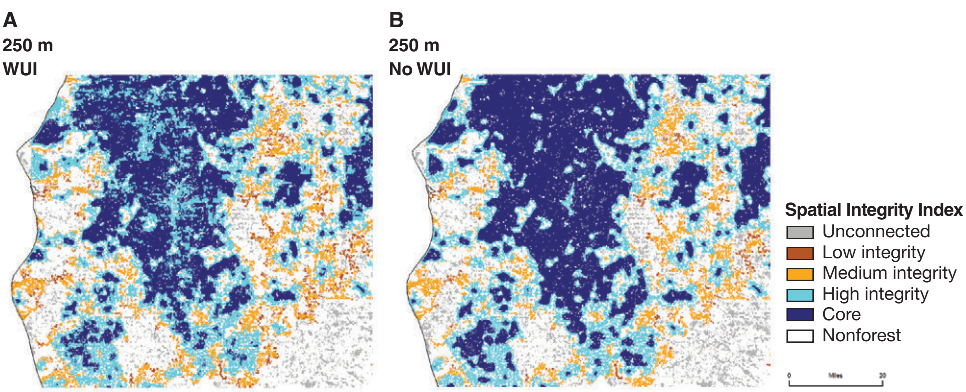

Figure 52.—Spatial integrity index of forest land at the 250 m scale with (A) and without (B) wildland-urban interface intermix for a region north of Grand Rapids, Michigan. For data source and description of this map, see appendix 2.

Roads remain pervasive in the landscape, often hidden from aerial view throughout large areas of continuous canopy. Sixty-six percent of Michigan's forest land is within 1,310 feet of a road (Fig. 53). In the Upper Peninsula, 31 percent of forest was within 650 feet of a road versus 46 and 43 percent for the northern and southern portions of the Lower Peninsula, respectively (Table 10). Much of this area may coincide with WUI housing development but the data set is missing many minor roads not associated with housing development. Including these missing roads doubles densities in areas like northern Wisconsin (Hawbaker and Radeloff 2004).

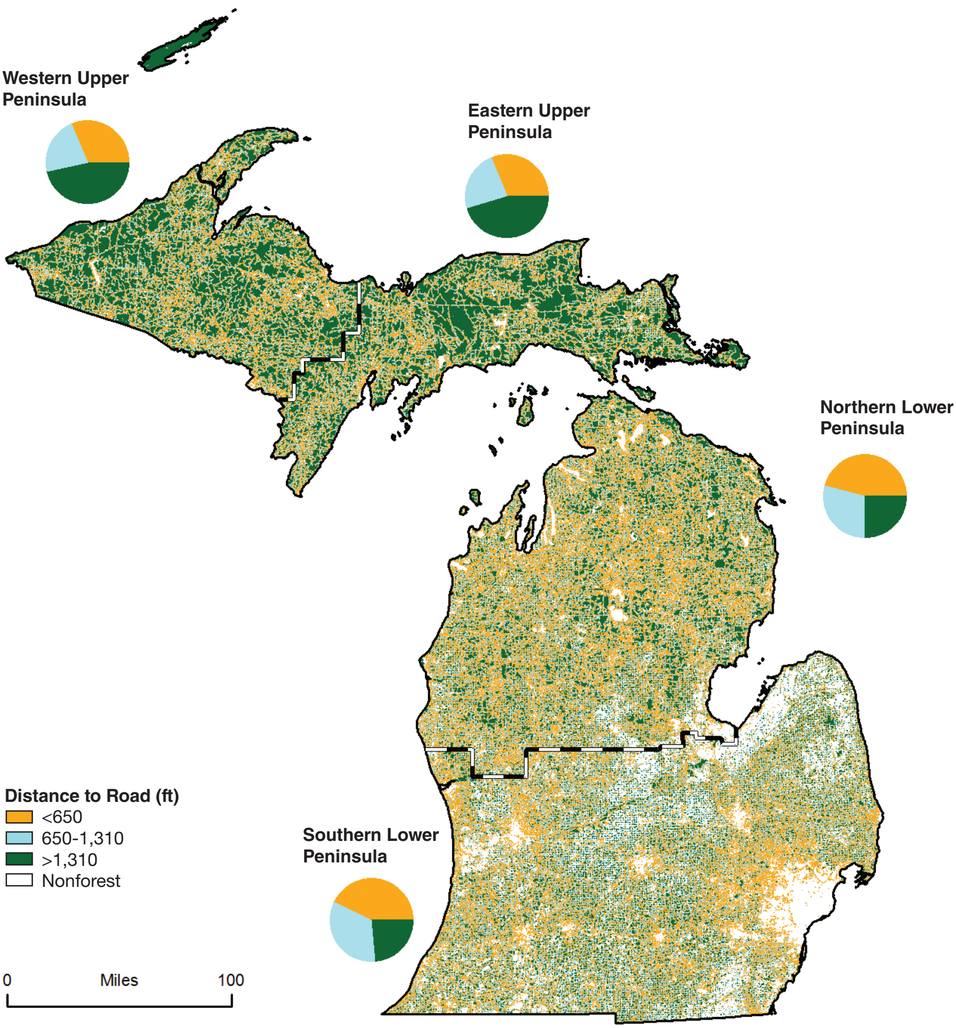

Figure 53.—Distance to nearest road for forest land, Michigan. For data source and description of this map, see appendix 2.

What this means

Using SII at either scale, 66 to 69 percent of Michigan's forest land is core forest and 10 to 12 percent is in fragments or has low spatial integrity. Statewide, core forest drops 8 to 10 percentage points upon removing WUI areas, but the effect is more prevalent in the southern Lower Peninsula. Accounting for roads further reduces integrity in some areas.

Fragmentation and urbanization are changing how Michigan's forests function, affecting their ability to supply forest products and ecosystem services. As housing development continues to sprawl into rural areas, fragmentation is a growing concern to land managers as forest stewardship becomes increasingly difficult. Factors that increase fragmentation, such as development incursions into core and high integrity forest areas, should be the focus of conservation and planning activities. In addition, impacts on the resilience of forests should be considered when maintaining and developing roads.

Down Woody Materials

Background

Down woody materials (DWM) in the form of fallen trees, branches, litterfall, and duff fill a critical ecological component of Michigan's forests. They provide wildlife habitat such as dens for black bears and shelter for small mammals (Harmon et al. 1986). Invertebrates can thrive in their damp, dark environment and the invertebrates are a food source for larger animals. The microclimate of moisture, shade, and nutrients often helps with establishment of floral regeneration (Harmon et al. 1986). DWM are important carbon stocks (Woodall et al. 2013) and may be a source of fuel for bioenergy industries. In times of extreme fire weather (e.g., drought), DWM may constitute a fire hazard that should be monitored (Woodall et al. 2005). Carbon pools, fuels, forest structure, and wildlife habitat can be measured to some degree with estimates of DWM (Woodall 2007, Woodall and Monleon 2008).

DWM was measured in the field from 2002 through 2010 as part of the P3 inventory (see Gormanson et al. 2017). DWM in coarse (CWD) and fine woody (FWD) debris and dead wood piles was estimated from 211 P3 plots in Michigan visited from 2006 thru 2010. CWD includes individual woody pieces at least 3 inches in diameter and represents the 1,000+-hr fuel loading class. FWD are individual woody pieces smaller than CWD and represent the 1-hour, 10-hour, and 100-hour fuel loading classes at 0.01 to 0.24, 0.25 to 0.99, and 1.00 to 2.99 inches in diameter, respectively. A dead wood pile is a group of CWD pieces in which it is impractical to acquire individual measurements of CWD pieces. CWD within a dead wood pile is calculated by measuring the pile volume and applying a visually estimated CWD density.

What we found

The total carbon stored in DWM on Michigan's forest land exceeded 54 million tons. Downed woody debris carbon was normally distributed by stand-age class with moderately aged stands having the highest total carbon (~19 million tons) (Fig. 54). The downed dead wood biomass within Michigan's forests is dominated by CWD at approximately 75 million tons (66 percent) while FWD accounts for 39 million tons (34 percent). Dead wood piles account for less than 1 percent. With the higher acreage in private forest land, it is not surprising that the total volume of CWD was highest on private ownership at approximately 5.5 billion ft^3 (Fig. 55). On a per-acre basis, CWD does not appear to differ significantly among ownership groups (437 million ft^3/acre). Privately owned forest land had the highest volume of dead wood in piles at over 42 million ft^3.

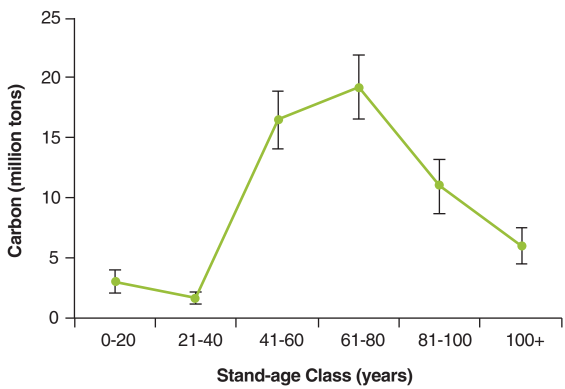

Figure 54.—Carbon in down woody materials (fine and coarse woody debris and piles) by stand-age class on forest land in Michigan, 2006 to 2010; error bars represent 68 percent confidence interval around estimate.

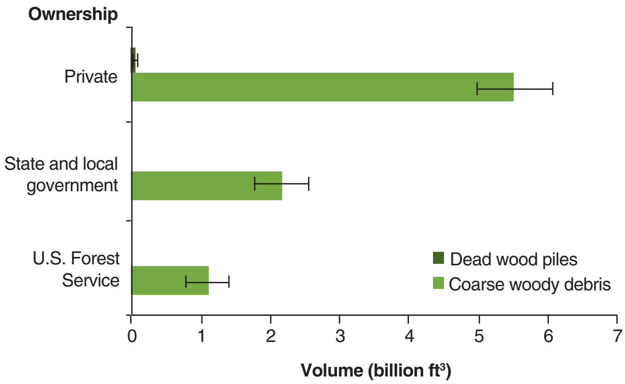

Figure 55.—Volume of coarse woody debris and dead wood piles on forest land by ownership group, Michigan, 2006 to 2010; error bars represent 68 percent confidence interval around estimate.

Compared to DWM fuel loadings in western states with large-scale wildfire events (e.g., California with 8.4 tons/acre) loadings are not exceedingly high in Michigan, Wisconsin, and Minnesota at 5.6, 4.5, and 6.0 tons/acre, respectively (Fig. 56). Michigan, Wisconsin, and Minnesota's fuel loadings do not differ across the 1- to 100-hour size-classes. The loadings of CWD (1,000+hr) for Michigan and Minnesota are each greater than loadings for Wisconsin. In Michigan, changes since the last inventory (2005) were small and it was not possible to confidently identify trends given the small sample size.

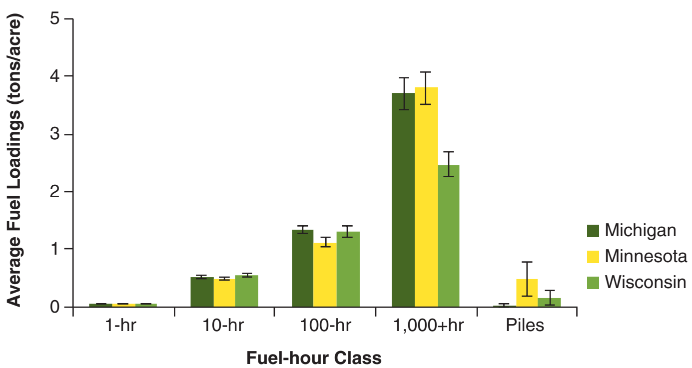

Figure 56.—Average fuel loadings by fuel-hour class on forest land for Michigan (2006 to 2010), Minnesota (2006 to 2010), and Wisconsin (2006 to 2010); error bars represent 68 percent confidence interval around estimate.

What this means

Although the carbon stocks of DWM are relatively small compared to those of soils and standing live biomass across Michigan (see Forest Carbon), it is still a critical component of the carbon cycle as a transitory stage between live biomass and other detrital pools such as litter. Beyond transition of dead wood carbon to other pools, if future temperature and precipitation patterns change (e.g., increase in temperature and precipitation) there is a potential for a reduction in these stocks due to increased rates of decay (Russell et al. 2014a, b). The loss of dead wood carbon stocks could indicate the reduction of other pools in the future. Compared to southeastern U.S. states where there is more widespread industrial management of forests (Woodall et al. 2013), there were relatively few dead wood piles sampled in this first DWM inventory of Michigan's forests. Given that most CWD volume was estimated to be in private ownership, it is the management of Michigan's private forests that may largely affect the future of down woody material contributions to statewide forest carbon stocks and wildlife habitat (i.e., stand structure).

Down woody fuel loadings in Michigan's forests differ little from those in neighboring states and are less than those of western states with large-scale wildfire events. For example, Idaho has nearly the same amount of forest land (21 million acres) but 1.8 times the amount of DWM. Given that fuels can only pose a fire danger when their moisture levels drop below levels that enable combustion, DWM fuels across Michigan are only fire hazards in certain areas and only in times of extreme drought. Although there is an appreciable amount of CWD habitat in Michigan's forests, most pieces are small (less than 8 inches) and predominately in moderate to advanced stages of decay.

Forest Carbon

Background

Tree biomass is approximately 50 percent carbon, based on dry weight. This mass of carbon has increasingly become a part of forest resource reporting in recent years. This is primarily because forests tend to sequester carbon from the atmospheric greenhouse gas carbon dioxide, which is linked to global change (FAO 2010). Among terrestrial ecosystems, forests contain the largest reserves of sequestered carbon. Regional and national greenhouse gas reporting forums include forest carbon stocks because increases in forest carbon stock represent quantifiable partial offsets to other greenhouse gas emissions. For example, carbon sequestration by U.S. forests represented an offset of over 11 percent of total U.S. greenhouse gas emissions in 2013 (U.S. EPA 2015) and the continuing increase in Michigan forest carbon stocks contributes to this effect. This section provides an overview of carbon in the State's forest lands.

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

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

What we found

Live trees and soil organic carbon account for 92 percent of forest carbon stocks, and 15 percent of carbon is in the boles of trees (wood and bark of trees at least 5 inches d.b.h.) (Fig. 57). Live tree carbon per acre varies slightly according to ownership (Table 11) with somewhat greater carbon density on federally owned public forest land. However, most carbon is in private ownership due to the greater amount of acreage in private forest land.

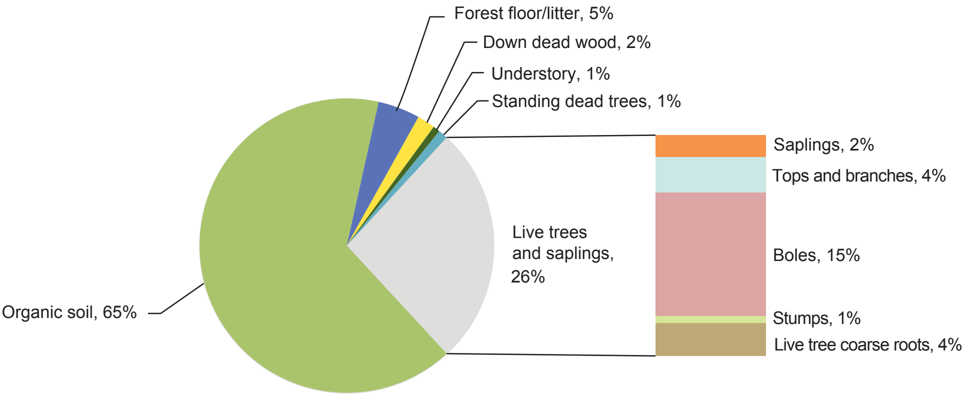

Figure 57.—Percentage of carbon on forest land by component, Michigan, 2014. Live tree carbon is subdivided into live saplings (at least 1 but less than 5 inches d.b.h.) and trees at least 5 inches d.b.h.

Table 11.—Live tree carbon and total forest ecosystem carbon by ownership group, Michigan, 2014

Ownership	Live tree carbon	Live tree carbon	Total ecosystem carbon
	tons/acre	*million tons*	*million tons*
Private	27	338	1,265
Federal	29	91	319
State and local government	23	108	461
Statewide	26	537	2,045

Aboveground carbon per acre increases with stand age, and greater net accumulation is within living plant biomass (Fig. 58). Total carbon stocks are the product of carbon per acre and total acres of forest within each stand-age class. Sixty percent of total aboveground carbon stocks occurs in two age classes, spanning 41 to 80 years; in contrast, the aggregate of youngest and oldest age classes accounts for 11 percent.

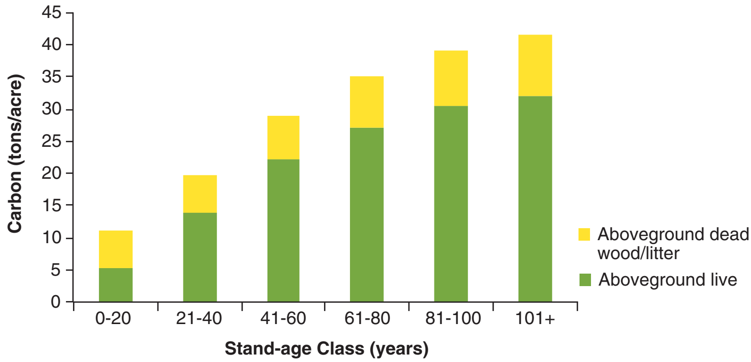

Figure 58.—Carbon by stand-age class for aboveground living plant biomass (live trees at least 1 inch d.b.h. and understory) versus dead wood (standing dead and down dead) and litter pools, Michigan, 2014.

Carbon stocks vary by species composition and associated forest type (Fig. 59). Carbon per acre is categorized into live biomass (tree and understory), dead wood (standing dead trees and down dead wood), litter, and soil. Much of the variability in carbon per acre is associated with the variability of live tree and understory biomass among forest types. However, northern white-cedar forest type has a relatively substantial amount of organic soil carbon per acre. The northern white-cedar type occurs predominately in hydric soils which normally maintain high amounts of organic matter. Twenty percent of total carbon stocks are in the sugar maple/beech/yellow birch forest type, followed by aspen (11 percent) and northern white-cedar (10 percent). Soil organic carbon in the sugar maple/beech/yellow birch type is the largest single pool at 233 million tons of carbon or about 11 percent of all Michigan forest carbon stocks.

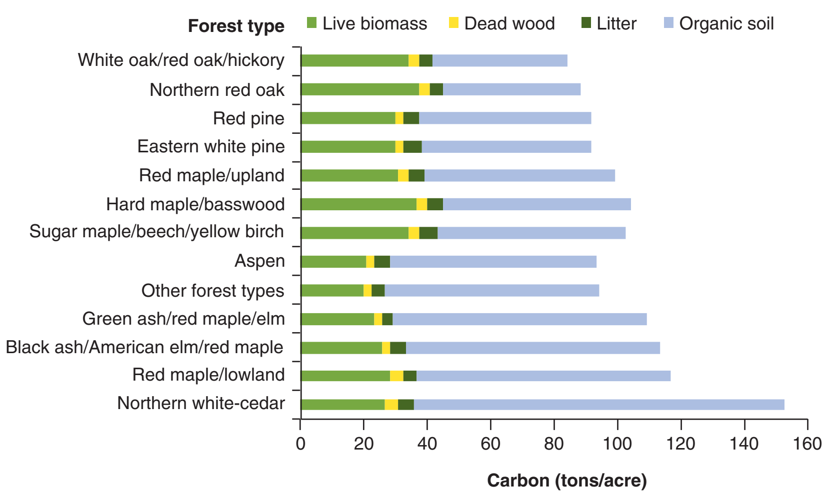

Figure 59.—Carbon stocks by forest type and category that comprise at least 2 percent of live tree aboveground carbon, Michigan, 2014.

Actual stocks for a particular forest stand vary because of a combination of factors such as site history, management, stand age, or component species. Statewide, fully-stocked stands have 33 tons carbon/acre in live trees but the site-to-site variability is such that 50 percent of measured plots fell between 25 and 43 tons carbon/acre (interquantile range of 25 to 43 tons carbon/acre). Analogously, the interquantile range is 10 to 31 for Minnesota (2013 inventory) and 21 to 41 for Wisconsin (2014 inventory).

Total forest ecosystem carbon stocks are 2,045 million tons for the 2014 inventory. Forest ecosystem carbon per acre increased by 0.8 percent relative to the 2009 inventory, but average live tree carbon per acre increased by 5.5 percent. In addition, total forest area increased over the same period resulting in a 2.8 percent increase in total carbon stocks from 2009 to 2014.

What this means

Forest carbon stocks or differences in stock broadly reflect other measures of forest resources such as stand age, volume, or stocking. Estimates reported here provide comparisons to other states' carbon stocks. For example, Michigan's forests represent 43 percent of the live tree forest carbon for the Lake States (MI, MN, and WI) and this stock ranks eleventh among the 48 conterminous states (U.S. EPA 2015). To summarize for Michigan: 1) most of the carbon is in soils (followed by live trees); 2) most of the carbon is in stands of 41 to 80 years; 3) specific stand-level carbon varies; and 4) overall forest carbon has increased over the past 5 years.

Forest Wildlife Habitat

Background

Forests, woodlands, and savannas provide habitats for 167 species of Michigan birds, 50 species of mammals, and 33 species of amphibians and reptiles (NatureServe 2011). Like all states, Michigan has developed a comprehensive wildlife conservation strategy, also known as a State Wildlife Action Plan (SWAP). Michigan's Plan was completed in 2005 (Eagle et al. 2005) and is currently in revision. Species (and habitats) of greatest conservation need (SGCN) are listed in the plan, including forest habitats and forest-associated species of birds, mammals, reptiles, amphibians, plants, and invertebrates. Fourteen statewide conservation priority threats are listed in Michigan's plan, and at least four have direct relevance to forests. The two highest priority threats identified are invasive species (see Insects, Disease, and Decline and Invasive Plants) and fragmentation (see Urbanization and Fragmentation).

Some species of wildlife depend on early successional forests comprised of smaller, younger trees, while others require older, interior forests containing large trees with complex canopy structure. Yet other species inhabit the ecotone (edge) between different forest stages, and many require multiple structural stages of forests to meet different phases of their life history needs. For example, Michigan's SWAP lists some SGCN such as American woodcock (*Scolopax minor*) and golden-winged warbler (*Vermivora chrysoptera*) that require early successional forest habitat and others such as the blue-spotted salamander (*Ambystoma laterale*) and cerulean warbler (*Dendroica cerulea*) that require late successional forest. Abundance and trends in structural and successional stages (e.g., stand age and stand size) serve as indicators of population carrying capacity for wildlife species (Hunter et al. 2001). Here, we use stand age and stand size (see Forest and Timberland Area) in a "coarse filter" scale analysis of conservation. Michigan's SWAP primarily uses a coarse filter approach, supplemented by a species-based fine filter approach for selected species having unique requirements (Eagle et al. 2005).

We also investigate standing dead trees, addressing conservation at the "mesofilter" scale, at which specific habitat features (e.g., standing dead trees, riparian forest strips) could serve particular habitat requirements for multiple species. Specific habitat features such as nesting cavities and standing dead trees provide critical habitat components for many forest-associated wildlife species. Standing dead trees that are large enough to meet habitat requirements for wildlife are referred to as snags. According to one definition, "…for wildlife habitat purposes, a snag is sometimes regarded as being at least 10 in (25.4 cm) in diameter at breast height and at least 6 ft (1.8 m) tall" (Society of American Foresters 1998). Michigan's SWAP identifies several SGCN that are dependent upon snags, including silver-haired bat (*Lasionycteris noctivagans*) and Indiana bat (also known as Indiana myotis [*Myotis sodalist*]), both of which roost under the peeling bark of dead or dying trees or in tree cavities. Standing dead trees serve as important indicators not only of wildlife habitat, but also for past mortality events and carbon storage (see Forest Carbon). And, they serve as sources of down woody material (see Down Woody Materials), which also provides habitat features for wildlife. The number and density of standing dead trees, together with decay classes, species, and sizes, define an important wildlife habitat feature across Michigan's forests.

What we found

Small diameter stands comprise 18 percent of Michigan's timberland; there has been a 20 percent decrease in area of small diameter stands between 1980 and 2014, but the area has been stable since 2004 (Fig. 60). Medium-diameter stands, accounting for one-third of Michigan's timberland, have decreased 15 percent in area between 1980 and 2014. In contrast, the area of large diameter stands has increased by 68 percent since 1980, and now comprises nearly half of Michigan's timberland. Abundance of timberland has decreased for both young (0 to 20 years) and old (100+ years) age classes since 1980, but timberland older than 80 years has increased (Fig. 61).

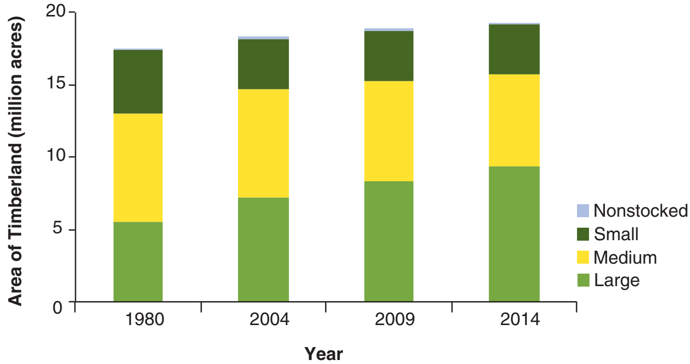

Figure 60.—Area of timberland by stand-size class and year, Michigan.

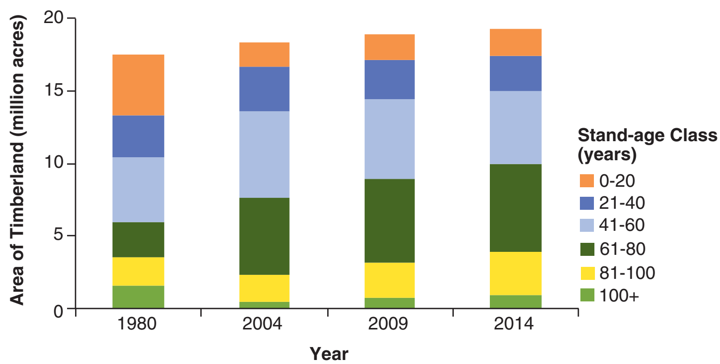

Figure 61.—Area of timberland by stand-age class and year, Michigan.

All three stand-size classes contain forests from all six age classes (Fig. 62). As expected, medium diameter stands are predominately forests of 41-80 years of age, with lower area in both younger and older forest. The area distribution in large diameter stands is slightly skewed with relatively more acreage in the 61 to 80 year age class and almost all forests of 100+ years of age. Forests of 0 to 20 years of age dominate the small diameter stands, with lesser amounts in each successive age class (Fig. 62). The area in small diameter stands has remained stable during the past decade, while young (0 to 20 years) forest may be slightly increasing. Large diameter stands have experienced an ongoing trend of increasing area, along with old (100+ years) forest area.

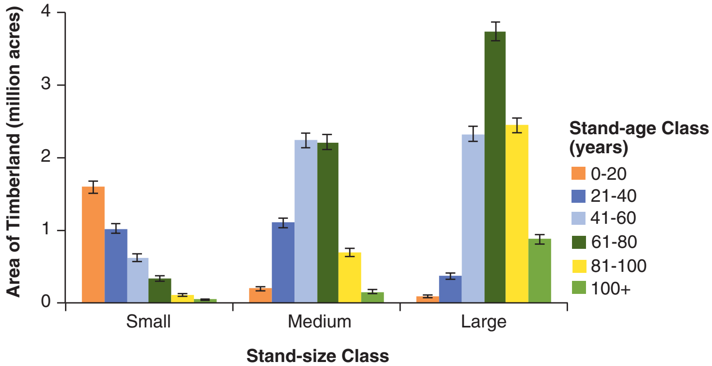

Figure 62.—Area of timberland by stand-size class and stand-age class (years), Michigan, 2014; error bars represent 68 percent confidence interval around estimate.

FIA collects data on standing dead trees (at least 5 inches d.b.h.) in varying stages of decay. Michigan's forest land has more than 393 million standing dead trees or 19.4 standing dead trees/acre with slightly higher densities on public (21.5) versus private (18.1) ownerships. Minnesota and Wisconsin have 19.4 and 15.1 standing dead trees/acre on forest land, respectively. Species depicted in Figure 63 account for nearly 90 percent of standing dead trees on Michigan's forest land. The most abundant standing dead species is balsam fir (51 million trees). Most species with known issues related to succession and health have higher numbers of standing dead relative to live trees (Fig. 64). Northern white-cedar (5) and red maple (4) have low numbers of standing dead to live trees even though they rank sixth and seventh by number of standing dead trees, respectively. Green ash (8 to 31), white ash (10 to 22), and black ash (7 to 20) experienced the largest increases in standing dead trees per 100 live trees since 2009. Since 2009, American beech (not shown in Fig. 64) was the other major species that had a substantial increase (4 to 13) in standing dead trees per 100 live trees.

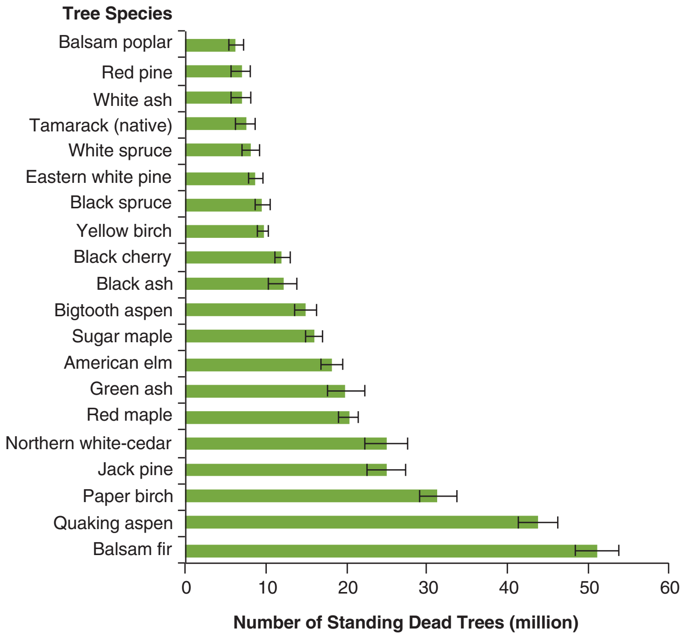

Figure 63.—Number of standing dead trees (at least 5 inches d.b.h.) of species that comprise at least 2 percent of standing dead trees on forest land, Michigan, 2014. Error bars represent 68 percent confidence interval around estimate.

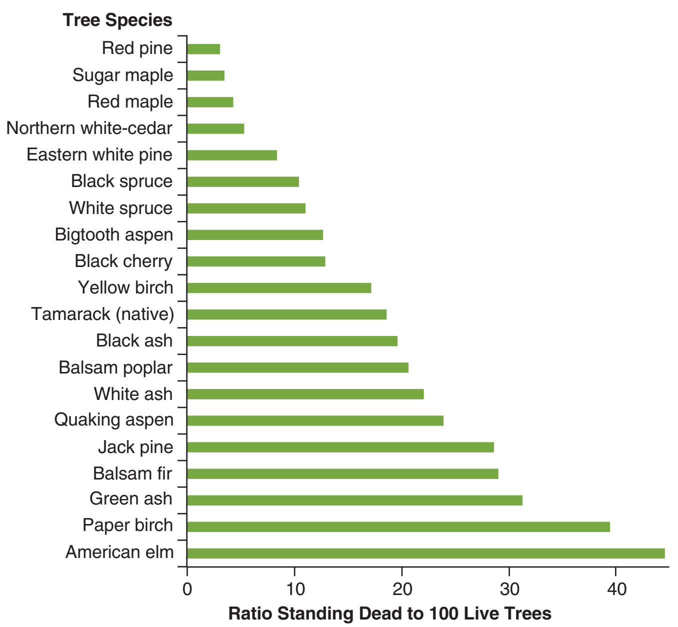

Figure 64.—Ratio of standing dead (at least 5 inches d.b.h.) to 100 live trees (at least 5 inches d.b.h.) on forest land for species that comprise at least 2 percent of standing dead trees, Michigan, 2014.

Over 83 percent of standing dead trees were smaller than 11 inches d.b.h., with 44 percent between 5 and 6.9 inches d.b.h.; only 3 percent are over 17 inches (Fig. 65), which is a slightly smaller percentage than for live trees (at least 5 inch d.b.h.) that are over 17 inches (4 percent). The largest percentage of standing dead trees is the middle decay class (only limb stubs present; 29 percent); the classes of least decay (all limbs and branches present) and most decay (no evidence of branches remain) comprise the smallest percentages (15 and 10 percent, respectively). Distribution of decay classes is similar across diameter classes, but larger trees tend to have relatively greater amounts of decay (Fig. 65).

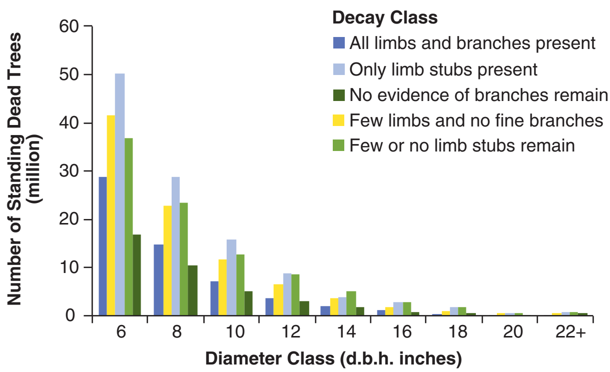

Figure 65.—Distribution of decay class by diameter class for standing dead trees at least 5 inches d.b.h. on forest land, Michigan, 2014.

What this means

Since 1980, Michigan's forests have grown older and larger. Both stand-size class and stand-age class are indicators of forest structural and successional stages and are generally consistent in Michigan. However, a very small area of old forest (100+ years) is in small diameter stands and a very small area of young forest (0 to 20 years) is in large diameter stands. Large diameter stands include the greatest age heterogeneity with mixtures of various aged or sized trees providing a vertical diversity of vegetation structure that can enhance habitat conditions for some species. Managing forest conditions in both younger and older age classes (and smaller and larger structural stages) to maintain both early and late successional habitats for a diversity of forest-associated species may conserve habitat and viable populations of many forest-associated wildlife species.

Snags and smaller standing dead trees result from a variety of potential causes, including diseases and insects, weather damage, fire, flooding, drought, competition, and other factors. The number of standing dead trees relative to live trees increased for ash and American beech due primarily to EAB and BBD, respectively. These species also have relatively higher amounts of basal area in live trees with poor crowns (see Tree Crown Health and Damage).

Some standing dead trees are natural and desirable for forest health. Dead trees may contain significantly more cavities per tree than occur in live trees (Fan et al. 2003), thereby providing habitat features for foraging, nesting, roosting, hunting perches, and cavity excavation for wildlife, from primary colonizers such as insects, bacteria, and fungi to birds, mammals, and reptiles. In Michigan, both the federally endangered Indiana bat and federally threatened northern long-eared bat (*Myotis septentrionalis*) roost under exfoliating bark of several species of large trees (16 to 27 inches d.b.h.); dead trees comprise about half of the roost trees for northern long-eared bat and nearly all the roost trees for Indiana bat (Foster and Kurta 1999). Most cavity nesting birds are insectivores that help to control insect populations. The availability of very large snags may be a limiting meso-scale habitat feature for some species of wildlife. Providing a variety of forest structural stages and retaining specific features like snags on both private and public lands are ways that forest managers maintain the abundance and quality of habitat for forest-associated wildlife species in Michigan.

Forest Socioeconomics

Forwarder. Photo by Dave Kenyon, MI DNR, used with permission.

Family Forest Owners

Background

How land is managed is primarily the owner's decision. Therefore, to a large extent, landowners determine the availability and quality of forest resources, including recreational opportunities, timber, and wildlife habitat. By understanding the priorities of forest land owners, the forest conservation community can better help owners meet the owners' needs, and in so doing, help conserve the State's forests for future generations. The National Woodland Owners Survey (NWOS: www.fia.fs.fed.us/nwos), conducted by FIA, collects and analyzes information on private forest landowners' attitudes, management objectives, and concerns (Gormanson et al. 2017). It focuses on the diverse and dynamic group of owners that is the least understood—families, individuals, and other unincorporated groups, collectively referred to as "family forest owners." The NWOS data reported here are based on the responses from 271 family forest ownerships from Michigan that participated between 2011 and 2013, the 2013 NWOS (Butler et al. 2016). An ownership is a legal entity that has proscribed legal rights over a specific resource. In the case of family ownerships, it is composed of one or more owners (i.e., individuals).

What we found

Family forest owners own most private forest land in Michigan (9.1 of 12.6 million acres). According to the NWOS, there are an estimated 192,000 family forest ownerships across Michigan that each own at least 10 acres of forest land, a collective 8.4 million acres. The average forest holding of this group is 44 acres; 76 percent of these family forest ownerships own less than 50 acres of forest land, but 62 percent of the family forest land is in holdings of at least 50 acres (Fig. 66). The average size of forest holdings did not change appreciably since the previous NWOS in 2006. The primary reasons for owning forest land are related to wildlife, aesthetics, and privacy (Fig. 67). The most common activities on their land are personal recreation, such as hunting and hiking, and cutting trees for personal use, such as firewood (Fig. 68). Most family forest ownerships have not participated in traditional forestry management and assistance programs in the past 5 years (Fig. 69); the most common occurrence is having received management advice, but this is only about 13 percent of the ownerships. While the number of ownerships with a management plan increased since 2006 (4.4 to 8.2 percent), the number having received advice decreased (18.8 to 13 percent). The average age of family forest owners in Michigan is 63 years with 51 percent of the family forest land owned by people who are at least 65 years of age (Fig. 70); the analogous estimate for 2006 was lower at 35 percent.

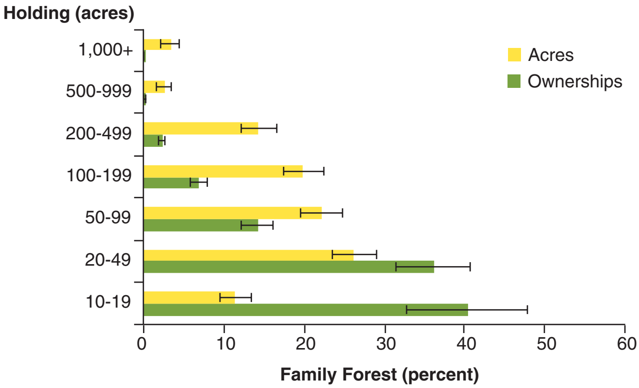

Figure 66.—Percentage of family forest ownerships and acres of forest land by size of forest land holdings, Michigan, 2013; error bars represent 68 percent confidence interval around estimate.

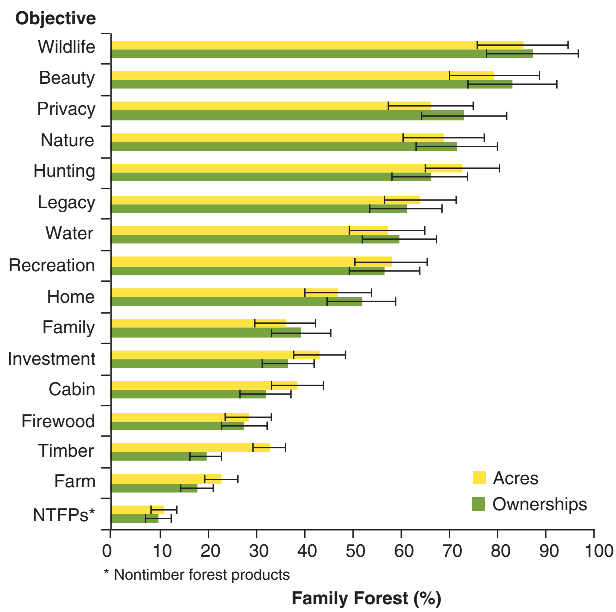

Figure 67.—Percentage of family forest ownerships and acres of forest land by reasons for owning forest land ranked as very important or important, Michigan, 2013. Categories are not exclusive; error bars represent 68 percent confidence interval around estimate.

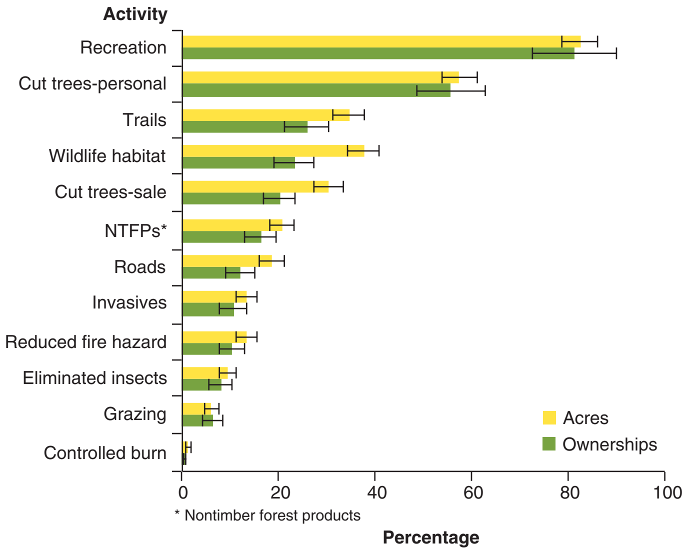

Figure 68.—Percentage of family forest ownerships and acres of forest land by activities in the past 5 years, Michigan, 2013. Categories are not exclusive; error bars represent 68 percent confidence interval around estimate.

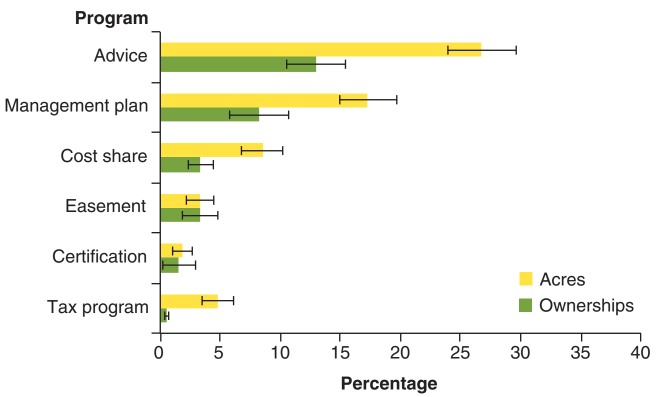

Figure 69.—Percentage of family forest ownerships and acres of forest land by participation in forest management programs, Michigan, 2013. Categories are not exclusive; error bars represent 68 percent confidence interval around estimate.

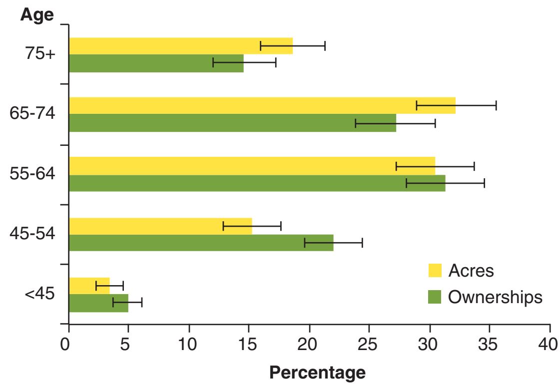

Figure 70.—Percentage of family forest ownerships and acres of forest land by age of primary owner, Michigan, 2013; error bars represent 68 percent confidence interval around estimate.

What this means

The fate of forests lies primarily in the hands of those who own and control the land. It is therefore critical to understand forest owners and what policies and programs can help them conserve the forests for current and future generations. Looking at family forest ownerships, the group that is the least understood and whose land has arguably the most uncertain future, they own their land primarily for amenity reasons but many are actively doing things with their land. That stated, more than 90 percent of them do not have a management plan and most have not participated in any other traditional forest management planning or assistance programs. There are significant opportunities to help these owners increase their engagement and stewardship of their lands. Programs such as Tools for Engaging Landowners Effectively (http://www.engaginglandowners.org) can help the conservation community develop and implement programs more effectively and efficiently. Another important trend to watch is the aging of the family forest owners. With many of them being relatively advanced in age, this portends many acres of land passing on to the next generation in the not too distant future. There are programs such as Your Land Your Legacy (http://masswoods.net/monthly-update/your-land-your-legacy-deciding-future-your-land) and Ties to the Land (http://tiestotheland.org) that are being implemented to help owners meet their bequest goals, but it is uncertain who the future forest owners will be and what they will do with their land.

Timber Product Output

Background

Michigan's wood-products and paper industries directly employ 34,951 workers and have an output of approximately $10.2 billion annually (Leefers 2016). These primary wood-using industries include sawmills, pulp and paper manufacturers, and veneer and plywood manufacturers. Additional Michigan wood-product jobs and economic outputs are in logging, transportation, trade, and wood furniture industries. To properly manage and sustain Michigan's forests, it is essential to have information on the location and species of timber that supply these industries.

Since the late 1970s, the Forest Service and the MIDNR have conducted surveys of all primary and wood using mills in Michigan. These surveys typically result in assessment reports on timber product output and use. Timber product output is the volume of industrial roundwood products produced. Industrial roundwood products include saw logs, pulpwood, veneer logs, poles, commercial posts, pilings, cooperage logs, particleboard bolts, shaving bolts, lath bolts, charcoal bolts, and chips from roundwood used for pulp or board products. In addition to surveys from Michigan, the assessments also include mill survey results from other states that processed wood harvested from Michigan and regional harvest utilization studies (FIA unpublished). Here, production considers only wood coming from the forests of Michigan and processed in the State or other locations.

The most recent survey for Michigan (Haugen 2016) was conducted for 2010 (Fig. 71); results from that survey are included in this report. The previous assessment (Haugen et al. 2014) is for 2008.

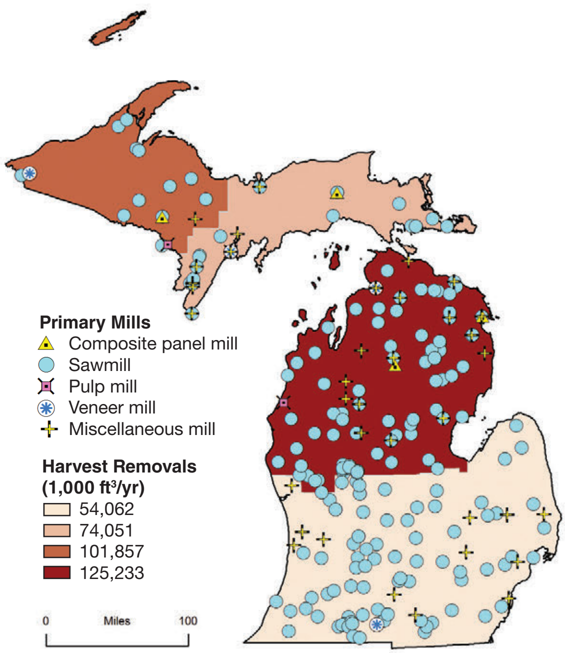

Figure 71.—Location and type of active, primary wood-using mills in Michigan (2010) overlaid on average annual harvest removals (2014 inventory) from plot data by FIA unit.

The TPO mill surveys determine the total industrial wood usage in the State from all land. From this total wood usage, regional harvest utilization studies are used to make estimates for the volume that came from timberland, forest land, and nonforest land. Also, estimates are produced for the volume from growing-stock trees, cull trees, dead trees, limbwood, nonforest-land trees, and other sources.

The average annual removals estimate (see Annual Removals) derived from FIA plot observations can differ from the TPO survey estimate. Average annual removals are based on FIA plot observations and include harvest removals, unutilized removals (trees killed in the harvesting process and left on site), and diversion removals. The TPO survey estimate is based on data from a single year. The average annual removals estimate is a yearly average from one inventory to the next. Both the TPO and plot observations can be used to derive estimates of harvest removals for growing stock from timberland, but because of different approaches and time periods, the estimates may be quite different. The TPO estimates for 2008 and 2010 averaged 315 million ft^3. The nearly analogous estimate from plot observations was 313 million ft^3 for the 2014 inventory (2005-2009 to 2009-2014).

What we found

In the process of harvesting industrial roundwood from Michigan's forests in 2010, 439 million ft^3 of woody material was removed. This woody material includes any tree (e.g., dead tree or sapling) and aboveground volume (1 foot stumps not included for pole- and sawtimber-size trees unless mill indicates processing of stumps). Seventy-seven percent of the woody material removed was used for industrial roundwood, 5 percent was logging residues (merchantable material left on site), and 18 percent was logging slash (unmerchantable material left on site). About 41 percent of the roundwood produced in Michigan was from the northern Lower Peninsula (Fig. 72).

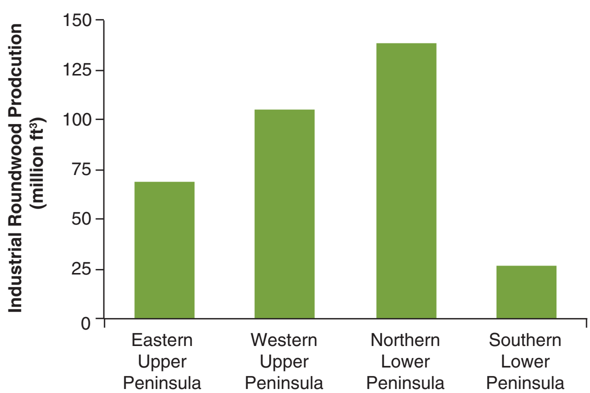

Figure 72.—Industrial roundwood production by region, Michigan, 2010.

Aspen accounted for just over 20 percent of the total industrial roundwood produced in 2010. Other important species or species groups harvested were red pine (16 percent), hard maple (15 percent), soft maple (10 percent), red oaks (6 percent), and jack pine (4 percent) (Fig. 73).

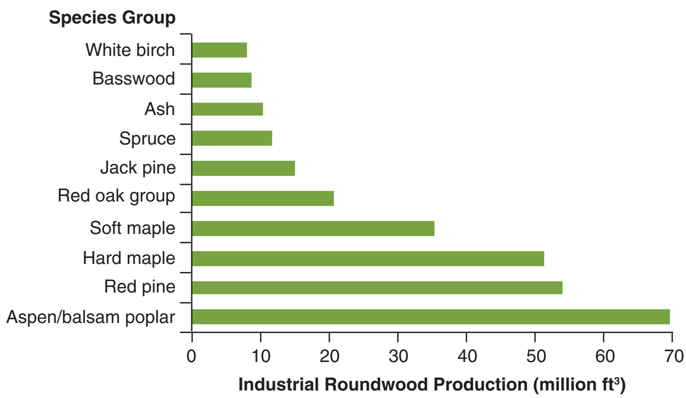

Figure 73.—Industrial roundwood production by prominent species group, Michigan, 2010.

By product, pulpwood accounted for 52 percent of all the roundwood produced, saw logs represented 38 percent, and veneers, industrial fuelwood, and other miscellaneous items accounted for 10 percent (Fig. 74).

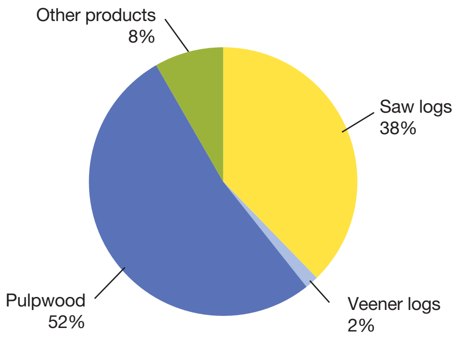

Figure 74.—Proportion of industrial roundwood production by product, Michigan, 2010.

Michigan's saw-log production was 746.2 million board feet in 2010 and 93 percent of this was processed by Michigan mills. The remaining 7 percent was exported to mills in Wisconsin, Indiana, Ohio, Canada, or other countries (Fig. 75).

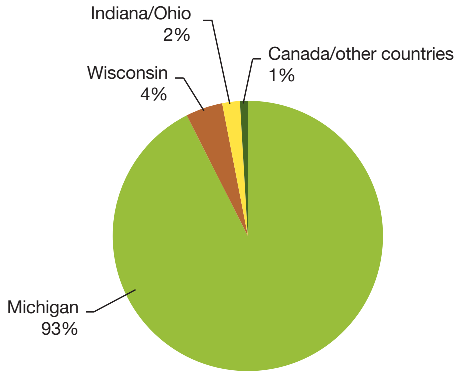

Figure 75.—Saw-log production by state or country of destination, Michigan, 2010.

Michigan mills processed about 744.1 million board feet. Ninety-three percent of this was from Michigan's forests with the other 7 percent imported from Wisconsin (6.5 percent), Illinois, Indiana, and Canada.

More than 2.25 million cords of pulpwood (mill residue not included) were produced from Michigan forest lands in 2010, of which 1.9 million cords (84 percent) remained in Michigan. Michigan exported 283,000 cords of this pulpwood to Wisconsin, 58,000 cords to Minnesota, and over 7,000 cords went to mills in Canada (Fig. 76). Michigan mills processed 2.07 million cords of pulpwood. As previously mentioned, 1.9 million cords originated from Michigan. Another 172,000 cords of pulpwood were imported from Wisconsin and Canada by Michigan pulp and composite panel mills.

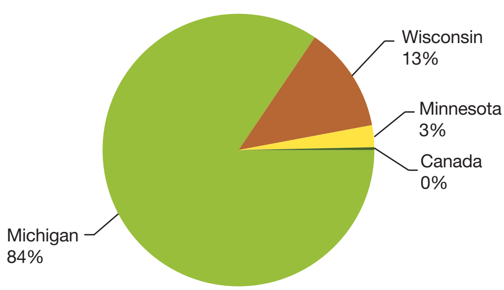

Figure 76.—Pulpwood production by state or country of destination, Michigan, 2010.

Between 2008 and 2010, industrial roundwood production decreased by 2 percent (Fig. 77). Saw-log production increased by 14 percent and pulpwood decreased by nearly 5 percent. Another pulpwood mill closed in 2010 leaving three active pulpwood mills in the State. The State maintained four active composite panel mills. Industrial roundwood used for other products has declined since 2008 from 46.3 to 33.7 million ft^3.

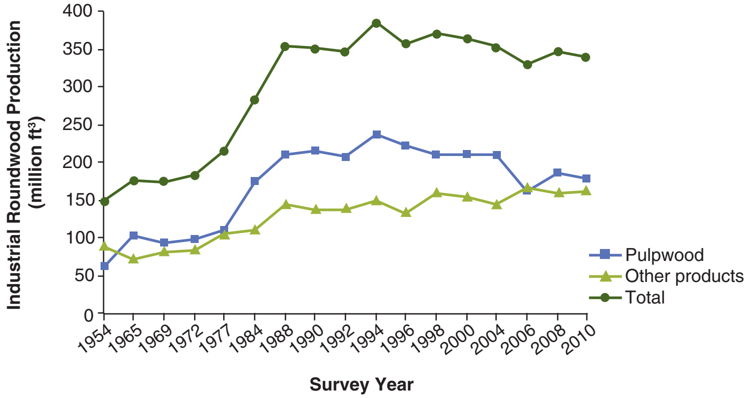

Figure 77.—Production of industrial roundwood by product and year, Michigan.

According to previous mill surveys, the number of active primary wood-using mills in Michigan decreased from 405 mills in 1990 to 309 mills in 2000, and to 283 mills in 2008 (Table 12). Results from the 2010 TPO survey show a loss of 20 more mills, indicating a slower overall recovery then anticipated within the industry.

Table 12.—Active primary wood-using mills in Michigan by survey year (pulp/composite panel mills include particle board plants, OSB, and waferboard; other mills include posts, poles, piling, cooperage, shavings, and mine timber)

Mill type	Size	1990	1992	1994	1996	1998	2000	2004	2006	2008	2010
		number of mills									
Sawmill	>5 million board feet	29	31	38	31	38	36	40	42	33	37
Sawmill	1 to 5 million board feet	106	108	100	97	95	82	65	66	58	47
Sawmill	<1 million board feet	209	185	151	160	155	144	129	135	144	132
Pulp/composite panel mill		11	11	11	12	12	12	12	8	8	7
Veneer mill		7	7	5	4	5	5	4	4	4	4
Other mill		43	24	24	28	31	30	26	31	36	36
Total mills		405	366	329	332	336	309	276	286	283	263

What this means

As in the past, the northern Lower Peninsula was the largest producer of roundwood with more than 138.9 million ft^3 (41 percent of total); the western Upper Peninsula produced 104 million ft^3 (31 percent of total). This is not surprising as the northern Lower Peninsula and western Upper Peninsula account for the majority of timberland with 7.3 and 4.5 million acres, respectively.

Aspen is the most commonly harvested species in the State. This is partly due to the strong competitive nature of the pulp, paper, and OSB/panel industries. The relatively large amount of hard and soft maple produced is likely a function of both its availability and its desirability as a commercial species (lumber, veneer, and pulpwood). An estimated 685,929 cords of aspen and 654,633 cords of maple (hard and soft) were harvested for pulpwood in 2010, accounting for 60 percent of all pulpwood harvested in the State.

Michigan is processing most of its own wood resources. More than 88 percent of the roundwood harvested in Michigan is processed by Michigan mills. Production and total mill output has remained fairly steady while the number of active mills appears to be in decline. The number of active pulp and composite panel mills dropped to seven in 2010. Stiff competition from foreign paper mills appears to be influencing the loss of mills not only in Michigan but across the country over the last 10 years. While saw-log production rebounded from the 2008 housing recession, increasing more than 14 percent between 2008 and 2010, pulpwood production decreased nearly 5 percent. A 37 percent decrease in industrial fuelwood production between 2008 and 2010 contributed to the overall decrease of 27 percent or 12.6 million ft^3 in the other miscellaneous items category in 2010. The large decrease in industrial fuelwood production may have been caused in part by the abundant supply of natural gas and decrease in cost from 2008 to 2010. In Michigan, the average annual cost of industrial natural gas per thousand ft^3 dropped from \$10.26 to \$9.25; other parts of the country witnessed greater decreases (U.S. Energy Information Administration 2015).

There is an abundance of sustainable wood resources in the State based on the ratio of net growth to removals (see Net Growth to Removals) and current volumes (see Volume; Sawtimber Volume and Quality). Net growth, removals, and volume indicate that an increase in the harvest of timber products in Michigan would be biologically sustainable. This opportunity to increase harvest is influenced by difficult-to-measure factors such as landowner objectives, accessibility, parcelization, stumpage price, and market volatility, all of which make it more difficult to increase the harvest level in Michigan.

Future Forests of Michigan

Background

This section focuses on anticipated changes to the forests of Michigan between 2010 and 2060. The analysis is derived from the Northern Forest Futures study (Shifley and

Moser 2016). A large component of future forest change will be the result of normal forest growth, aging, natural regeneration, and species succession. In addition, the following external forces will drive forest change:

- Population increases will cause roughly 913,000 acres of forest land to be converted to urban land (Nowak and Walton, 2005).
- Economic conditions will affect forest products consumption, production, and harvest rates.
- Invasive species will spread and affect forest change.
- Changes in population, the economy, energy consumption, and energy production will affect future climate change.
- Climate change will affect patterns of forest growth and species succession.

The Northern Forest Futures study utilized several alternative scenarios that cover a range of different assumptions about the economy, population, climate, and other driving forces. The assumptions were incorporated into analytical models that estimated how northern forests are likely to change under each alternative scenario. The seven scenarios (A1B-C, A1B-BIO, A2-C, A2-BIO, A2-EAB, B2-C, and B2-BIO) are based on a storyline and storyline variation. They are identified by their storyline identifier (A1B, A2, or B2) followed by a hyphen and then their storyline variation (C, BIO, or EAB).

The three storylines:

1) A1B—Rapid economic globalization; international mobility of people, ideas, and technology; strong commitment to market-based solutions and education; high rates of investment and innovation in education, technology, and institutions at the national and international levels; a balanced energy portfolio including fossil intensive and renewable energy sources. This storyline uses the CGCM3.1 climate model (CCCM n.d.b).
2) A2—Consolidation into economic regions; self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions; technology diffuses more slowly than in the other scenarios; international disparities in productivity, and hence per-capita income, are largely maintained or increased in absolute terms; uses the CGCM3.1 climate model (CCCM n.d.b).
3) B2—A trend toward local self-reliance, stronger communities, and community-based solutions to social problems; energy systems differ from region to region, depending on the availability of natural resources; the need to use energy and

other resources more efficiently spurs the development of less carbon-intensive technology in some regions; uses the CGCM2 climate model (CCCM n.d.a).

The three storyline variations:

1) C—Continuation of the observed recent rates of forest removals due to timber harvesting and land use conversion from forest to another land use.

2) BIO—Increased harvest and utilization of woody biomass for energy variation; available for all three storylines (A1B, A2, and B2).

3) EAB—Potential impact of continued spread of EAB with associated mortality of all ash trees in the affected areas and continuation of the observed recent rates of forest removals due to timber harvesting and land use conversion from forest to another land use; available for only one scenario (A2).

What we found

The anticipated declines in forest land, which total in the hundreds of thousands of acres, reverse the trend of increasing forest area in Michigan since 1980 (Fig. 78). Specifically, over the next 50 years forest land area is projected to decline from an estimated 19.8 million acres in 2010 to 18.7 million acres (-6 percent) in 2060 under scenario A1B-C; to 18.9 million acres (-5 percent) under scenario A2-C; and to 19.2 million acres (-3 percent) under scenario B2-C. Only three scenarios are represented in Figure 78 as the climate model and variations on the storylines do not impact the area of forest land under this model. Only the storylines (developed around differing demographics and levels of economic activity) alter the area of forest land in the model. Scenarios with increasing population and economic activity have less forest land over the time period.

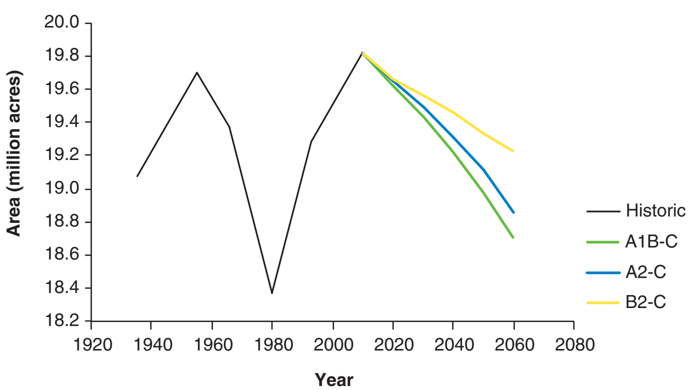

Figure 78.—Projected forest land area by scenario, Michigan, 2010 to 2060.

The area in the elm/ash/cottonwood forest-type group decreases under all scenarios from the historic level in 2010 but the decrease is largest under scenario A2-EAB (Fig. 79). The loss of the ash component in the elm/ash/cottonwood forest-type group is partially offset by increases in other associated species within the elm/ash/cottonwood group.

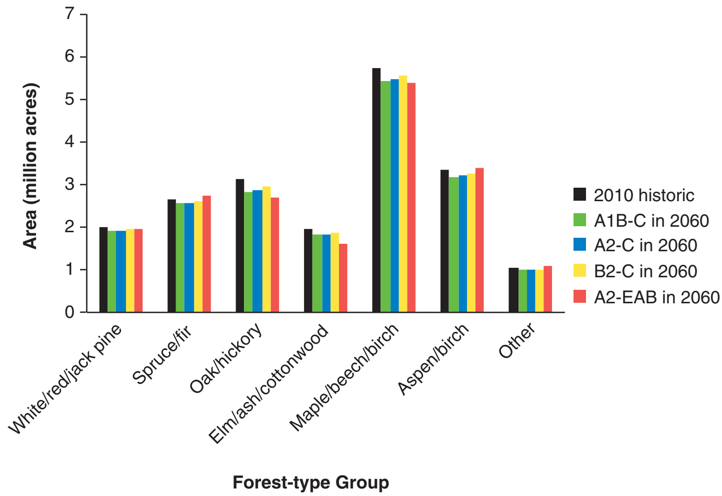

Figure 79.—Forest land area by forest-type group for 2010 inventory and projected 2060 scenarios, Michigan.

Emerald ash borer impacts are more pronounced (Fig. 80). Live tree volume on forest land increases for all but the A2-EAB scenario from 2010 to 2020. Not until 2060 do the three high biomass utilization variation scenarios (A1B-BIO, B2-BIO and A2-BIO) result in lower levels of live tree volume than the A2-EAB scenario. The volume under all scenarios is projected to decline until 2050 at which point the three standard scenarios (A1B-C, A2-C, and B2-C) and the A2-EAB scenario are projected to increase in volume (despite losses in forest land area) while the three high biomass utilization scenarios are projected to result in large decreases in volume from 2050 to 2060. The area of forest land is expected to decrease but the volume per acre is expected to increase under the standard scenarios as forests continue to mature. Scenarios with high biomass utilization expect increasingly high removals (Fig. 81) and volume per acre is expected to decrease.

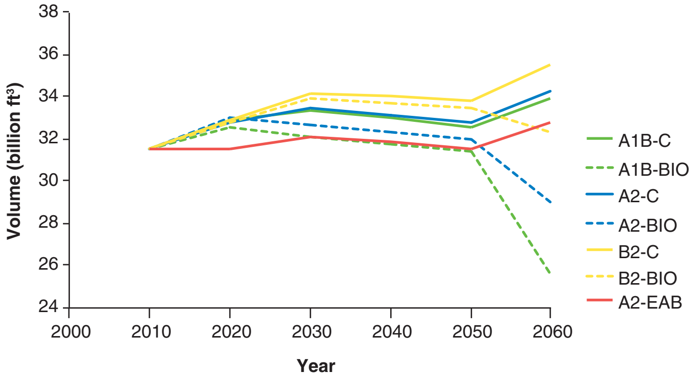

Figure 80.—Live tree volume on forest land by scenario, Michigan, 2010 to 2060.

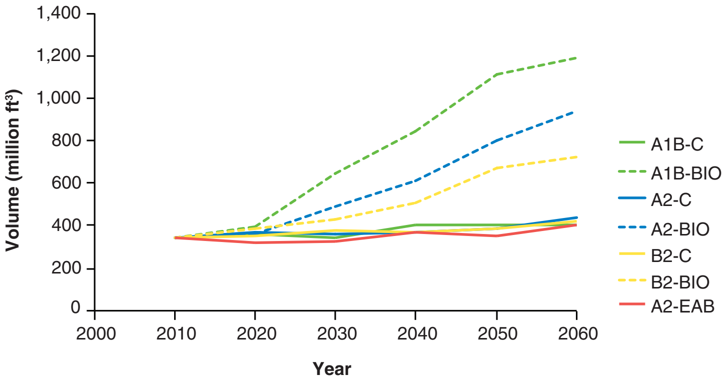

Figure 81.—Average annual growing-stock removals (harvest and land use conversion) on timberland in Michigan by scenario, 2010 to 2060.

What this means

Every storyline assumes that there will be an increase in population and economic activity; scenarios assuming greater increases in these two variables result in greater loss of forest land. Expecting a decrease in forest land area to abruptly occur after increasing for more than 30 years is difficult to understand and is only expected if assumptions are realized. Since 2010, estimates of forest land have continued to increase in Michigan and mostly in the southern Lower Peninsula which has the highest population. Michigan's population decreased 0.6 percent from 2000 to 2010 and increased 0.1 percent from 2010 to 2013 (U.S. Census Bureau 2015b).

In scenarios without high biomass utilization, the loss of forest land (3 to 6 percent) is somewhat offset by increases in volume. Every storyline shows an increase in removals over time but scenarios with high biomass utilization have substantially more removals, levels not seen over the last century, and a large impact on volume after 2050. These projections underscore the importance of continually monitoring Michigan's forest resources and accessing management impacts over time.

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Appendixes

Appendix 1. Tree Species

The following are tree species that were found on sample plots, Michigan, 2014. This is not a complete list of tree species known in Michigan.

Ailanthus or tree-of-heaven	*Ailanthus altissima*
American basswood	*Tilia americana*
American beech	*Fagus grandifolia*
American elm	*Ulmus americana*
American hornbeam, musclewood	*Carpinus caroliniana*
American mountain-ash	*Sorbus americana*
American sycamore	*Platanus occidentalis*
Apple spp.	*Malus* spp.
Austrian pine	*Pinus nigra*
Balsam fir	*Abies balsamea*
Balsam poplar	*Populus balsamifera*
Bebb willow	*Salix bebbiana*
Bigtooth aspen	*Populus grandidentata*
Bitternut hickory	*Carya cordiformis*
Black ash	*Fraxinus nigra*
Black cherry	*Prunus serotina*
Black locust	*Robinia pseudoacacia*
Black maple	*Acer nigrum*
Black oak	*Quercus velutina*
Black spruce	*Picea mariana*
Black walnut	*Juglans nigra*
Black willow	*Salix nigra*
Blackgum	*Nyssa sylvatica*
Blue ash	*Fraxinus quadrangulata*
Blue spruce	*Picea pungens*
Boxelder	*Acer negundo*
Bur oak	*Quercus macrocarpa*
Butternut	*Juglans cinerea*
Cherry and plum spp.	*Prunus* spp.
Chinkapin oak	*Quercus muehlenbergii*
Chokecherry	*Prunus virginiana*
Cockspur hawthorn	*Crataegus crus-galli*
Common serviceberry	*Amelanchier arborea*
Douglas-fir	*Pseudotsuga menziesii*
Eastern cottonwood	*Populus deltoides*
Eastern hemlock	*Tsuga canadensis*
Eastern hophornbeam	*Ostrya virginiana*
Eastern redbud	*Cercis canadensis*

(Appendix continued on next page.)

(Appendix 1. continued)

Eastern redcedar	*Juniperus virginiana*
Eastern white pine	*Pinus strobus*
European alder	*Alnus glutinosa*
Fir spp.	*Abies* spp.
Flowering dogwood	*Cornus florida*
Green ash	*Fraxinus pennsylvanica*
Hackberry	*Celtis occidentalis*
Hawthorn spp.	*Crataegus* spp.
Honeylocust	*Gleditsia triacanthos*
Jack pine	*Pinus banksiana*
Larch spp.	*Larix* spp.
Loblolly pine	*Pinus taeda*
Mockernut hickory	*Carya alba*
Mountain maple	*Acer spicatum*
Mountain-ash spp.	*Sorbus* spp.
Northern catalpa	*Catalpa speciosa*
Northern mountain-ash	*Sorbus decora*
Northern pin oak	*Quercus ellipsoidalis*
Northern red oak	*Quercus rubra*
Northern white-cedar	*Thuja occidentalis*
Norway maple	*Acer platanoides*
Norway spruce	*Picea abies*
Ohio buckeye	*Aesculus glabra*
Osage-orange	*Maclura pomifera*
Paper birch	*Betula papyrifera*
Pawpaw	*Asimina triloba*
Peachleaf willow	*Salix amygdaloides*
Pignut hickory	*Carya glabra*
Pin cherry	*Prunus pensylvanica*
Pin oak	*Quercus palustris*
Quaking aspen	*Populus tremuloides*
Red maple	*Acer rubrum*
Red mulberry	*Morus rubra*
Red pine	*Pinus resinosa*
Redcedar/juniper spp.	*Juniperus* spp.
Rock elm	*Ulmus thomasii*
Russian-olive	*Elaeagnus angustifolia*
Sassafras	*Sassafras albidum*
Scarlet oak	*Quercus coccinea*
Scotch pine	*Pinus sylvestris*
Serviceberry spp.	*Amelanchier* spp.

(Appendix continued on next page.)

(Appendix 1. continued)

Shagbark hickory	*Carya ovata*
Shingle oak	*Quercus imbricaria*
Shumard oak	*Quercus shumardii*
Siberian elm	*Ulmus pumila*
Silver maple	*Acer saccharinum*
Slippery elm	*Ulmus rubra*
Sour cherry, domesticated	*Prunus cerasus*
Striped maple	*Acer pensylvanicum*
Sugar maple	*Acer saccharum*
Swamp chestnut oak	*Quercus michauxii*
Swamp white oak	*Quercus bicolor*
Tamarack (native)	*Larix laricina*
White ash	*Fraxinus americana*
White mulberry	*Morus alba*
White oak	*Quercus alba*
White spruce	*Picea glauca*
White willow	*Salix alba*
Willow spp.	*Salix* spp.
Yellow birch	*Betula alleghaniensis*
Yellow-poplar	*Liriodendron tulipifera*

Appendix 2. Map Descriptions and Acknowledgments

Figure 1.
Data Sources: Regional Landscape Ecosystems of Michigan delineated by Dennis Albert and provided by the Michigan Geographic Data Library, 1995. FIA inventory unit boundaries from U.S. Forest Service, FIA, 2015.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 3.
Data sources: U.S. Forest Service, 2015; State of Michigan, 2014; The Conservation Biology Institute, 2010; U.S. Fish and Wildlife Service, 2015; U.S. National Park Service, 2015.
Base source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.
Note: Ownership does not include all State forest lands such as those from Michigan Department of Transportation.

Figure 4.
Data Source: U.S. Forest Service, 1955, 1980, 1993, and 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 8.
Data Sources: U.S. Forest Service, 2010. Forest-type groups assigned with nearest neighbor imputation from FIA field plots using 250-m Moderate Resolution Imaging Spectroradiometer imagery, National Land Cover Database, climate, and topographic data (Wilson et al. 2012).
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 18.
Data Source: U.S. Forest Service, 1955, 1980, 2009, and 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 19.
Data Source: U.S. Forest Service, 2010. Basal area assigned with nearest neighbor imputation from FIA field plots using 250-m Moderate Resolution Imaging Spectroradiometer imagery, National Land Cover Database, climate, and topographic data (Wilson et al. 2012).
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 26.
Data Source: Volumes and average annual net growth, mortality, and harvest removals from U.S. Forest Service, 2009 and 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.

Figure 37.
Data Source: U.S. Forest Service, FIA, 2012-2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographers: Scott A. Pugh and William H. McWilliams, U.S. Forest Service, June 2015.
Note: Depicted plot locations are approximate.

Figure 39.
Data Source: U.S. Forest Service, FIA, 2012-2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographers: Scott A. Pugh and William H. McWilliams, U.S. Forest Service, June 2015.
Note: Depicted plot locations are approximate.

Figure 42.
Data Source: U.S. Forest Service, FIA, 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh and Randall S. Morin, U.S. Forest Service, June 2015.
Note: Depicted plot locations are approximate.

Figure 47.
Data Source: U.S. Forest Service, FIA, 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographers: Scott A. Pugh and Cassandra M. Kurtz, U.S. Forest Service, June 2015.
Note: Depicted plot locations are approximate.

Figure 48.
Data Source: U.S. Forest Service, FIA, 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographers: Scott A. Pugh and Cassandra M. Kurtz, U.S. Forest Service, June 2015.
Note: Depicted plot locations are approximate.

Figure 49.
Data Source: U.S. Forest Service, FIA, 2009. Spatial integrity index assigned using forest cover derived from Wilson et al. (2012). Forest cover is at 250 m scale using 2009 FIA plot data.
Base Source: U.S. Census 2000 TIGER database, 2001.
Projection: Michigan GeoRef - NAD83.
Cartographer: Rachel I. Riemann and Scott A. Pugh, U.S. Forest Service, July 2015.

Figure 50.
Data Source: U.S. Forest Service, FIA 2009 (A) and 2006 (B). Spatial integrity index assigned using forest cover derived from Wilson et al. (2012) at 250 m scale (A) and National Land Cover Database (Fry et al. 2011) at 30 m scale (B).
Base Source: U.S. Census 2000 TIGER database, 2001.
Projection: Michigan GeoRef - NAD83.
Cartographer: Rachel I. Riemann and Scott A. Pugh, U.S. Forest Service, July 2015.

Figure 51.
Data Source: Wildland-urban interface (WUI) intermix areas from 2010 U.S. Census Bureau housing density and forest cover from 2011 National Land Cover Database (Jin et al. 2013). WUI is only shown where 2011 NLCD indicates forest.
Base Source: U.S. Census 2000 TIGER database, 2001.
Projection: Michigan GeoRef - NAD83.
Cartographer: Rachel I. Riemann and Scott A. Pugh, U.S. Forest Service, July 2015.

Figure 52.
Data Source: Spatial integrity index assigned using forest cover derived from Wilson et al. (2012). Forest cover is at 250 m scale using 2009 FIA plot data. Wildland-urban interface (WUI) intermix areas from 2010 U.S. Census Bureau housing density.
Base Source: U.S. Census 2000 TIGER database, 2001.
Projection: Michigan GeoRef - NAD83.
Cartographer: Rachel I. Riemann and Scott A. Pugh, U.S. Forest Service, July 2015.

Figure 53.
Data Source: Forest cover from 2001 NLCD (Homer et al. 2007) and roads from U.S. Census 2000 TIGER database, 2001.
Base Source: U.S. Census 2000 TIGER database, 2001.
Projection: Michigan GeoRef - NAD83.
Cartographer: Rachel I. Riemann and Scott A. Pugh, U.S. Forest Service, July 2015.

Figure 71.
Data Sources: Mills from U.S. Forest Service, Timber Product Output, 2010. Average annual harvest removals from U.S. Forest Service, FIA, 2014.
Base Source: Michigan Geographic Data Library, 2007.
Projection: Michigan GeoRef - NAD83.
Cartographer: Scott A. Pugh, U.S. Forest Service, April 2015.
Note: Depicted mill locations are approximate.

Appendix 3. Forest Types

Forest type is a classification of forest land based on and named for a composition of tree species that form a plurality of live tree stocking. If softwoods predominate (50 percent or more), then the forest type will be one of the softwood types and likewise for hardwoods. For the eastern United States, there are mixed hardwood-pine forest types when the pine and or redcedar (either eastern or southern) component is between 25 and 49 percent of the stocking. If the pine and or redcedar component is less than 25 percent of the stocking, then one of the hardwood forest types is assigned. The following are common or well known forest types in Michigan:

Jack pine: Associates—northern pin oak, bur oak, red pine, bigtooth aspen, paper birch, northern red oak, eastern white pine, red maple, balsam fir, white spruce, black spruce, and tamarack. Sites—dry to mesic sites. Softwood forest type that is a member of the white/red/jack pine forest-type group.

Red pine: Associates—eastern white pine, jack pine, red maple, northern red oak, white spruce, balsam fir, quaking aspen, bigtooth aspen, paper birch, northern pin oak. Sites—common on sandy soils but reaches best development on well drained sandy loam to loam soils. Softwood forest type that is a member of the white/red/jack pine forest-type group.

Eastern white pine/ eastern hemlock (includes Carolina hemlock): Associates— beech, sugar maple, basswood, red maple, yellow birch, gray birch, red spruce, balsam fir, black cherry, white ash, paper birch, sweet birch, northern red oak, white oak, chestnut oak, yellow-poplar, and cucumbertree. Sites—wide variety but favors cool locations, moist ravines, and north slopes. Softwood forest type that is a member of the white/red/jack pine forest-type group.

Eastern white pine: Associates—pitch pine, gray birch, aspen, red maple, pin cherry, white oak, paper birch, sweet birch, yellow birch, black cherry, white ash, northern red oak, sugar maple, basswood, hemlock, northern white-cedar, yellow-poplar, white oak, chestnut oak, scarlet oak, and shortleaf pine. Sites—wide variety but best development on well drained sands and sandy loams. Softwood forest type that is a member of the white/red/jack pine forest-type group.

Eastern hemlock (includes Carolina hemlock): Associates—white pine, balsam fir, red spruce, beech, sugar maple, yellow birch, basswood, red maple, black cherry, white ash, paper birch, sweet birch, northern red oak, and white oak. Sites—cool locations, moist ravines, and north and east slopes. Softwood forest type that is a member of the white/red/jack pine forest-type group.

Balsam fir: Associates—black, white, or red spruce; paper or yellow birch; quaking or bigtooth aspen, beech; red maple; hemlock; tamarack; black ash; or northern white-cedar. Sites—upland sites on low-lying moist flats and in swamps. Softwood forest type that is a member of the spruce/fir forest-type group.

White spruce: Associates—black spruce, paper birch, quaking aspen, red spruce, balsam fir, and balsam poplar. Sites—transcontinental; grows well on calcareous and well drained soils but is found on acidic rocky and sandy sites, and sometimes in fen peat lands along the maritime coast. Softwood forest type that is a member of the spruce/fir forest-type group.

Black spruce: Associates—white spruce, quaking aspen, balsam fir, paper birch, tamarack, northern white-cedar, black ash, and red maple. Sites—wide variety from moderately dry to very wet. Softwood forest type that is a member of the spruce/fir forest-type group.

Tamarack: Associates—black spruce, balsam fir, white spruce, northern white-cedar, and quaking aspen. Sites—found on wetlands and poorly drained sites. Softwood forest type that is a member of the spruce/fir forest-type group.

Northern white-cedar: Associates—balsam fir, tamarack, black spruce, white spruce, red spruce, black ash, and red maple. Sites—mainly occurs in swamps but also in seepage areas, limestone uplands, and old fields. Softwood forest type that is a member of the spruce/fir forest-type group.

Scotch pine: Common plantation species. Softwood forest type that is a member of the nonnative softwood forest-type group.

Eastern white pine/northern red oak/white ash: Associates—red maple, basswood, yellow birch, bigtooth aspen, sugar maple, beech, paper birch, black cherry, hemlock, and sweet birch. Sites—deep, fertile, well drained soil. Mixed hardwood-pine forest type and member of the oak/pine forest-type group.

Other pine/hardwood: A type used for those unnamed pine-hardwood combinations that meet the requirements for oak-pine. These are stands where hardwoods (usually oaks) comprise the plurality of the stocking with at least a 25 to 49 percent pine, eastern redcedar, or southern redcedar component. Mixed hardwood-pine forest type and member of the oak/pine forest-type group.

Post oak/blackjack oak (includes dwarf post oak): Associates—black oak, hickory, southern red oak, white oak, scarlet oak, shingle oak, live oak, shortleaf pine, Virginia pine, blackgum, sourwood, red maple, winged elm, hackberry, chinkapin oak, Shumard oak, dogwood, and eastern redcedar. Sites—dry uplands and ridges. Hardwood forest type and member of the oak/hickory forest-type group.

White oak/red oak/hickory (includes all hickories except water and shellbark hickory): Associates—pin oak, northern pin oak, chinkapin oak, black oak, dwarf chinkapin oak, American elm, scarlet oak, bur oak, white ash, sugar maple, red maple, walnut, basswood, locust, beech, sweetgum, blackgum, yellow-poplar, and dogwood. Sites—wide variety of well drained upland soils. Hardwood forest type and member of the oak/hickory forest-type group.

White oak: Associates—black oak, northern red oak, bur oak, hickory, white ash, yellow-poplar. Sites—scattered patches on upland, loamy soils but on drier sites than white oak/red oak/hickory forest type. Hardwood forest type and member of the oak/hickory forest-type group.

Northern red oak: Associates—black oak, scarlet oak, chestnut oak, and yellow-poplar. Sites—spotty distribution on ridge crests and north slopes in mountains but also found on rolling land, slopes, and benches on loamy soil. Hardwood forest type and member of the oak/hickory forest-type group.

Yellow-poplar/white oak/northern red oak: Associates—black oak, hemlock, blackgum, and hickory. Sites—northern slopes, coves, and moist flats. Hardwood forest type and member of the oak/hickory forest-type group.

Sassafras/persimmon: Associates—elm, eastern redcedar, hickory, ash, sugar maple, yellow-poplar, Texas sophora, and oaks. Sites—abandoned farmlands and old fields. Hardwood forest type and member of the oak/hickory forest-type group.

Chestnut oak/black oak/scarlet oak: Associates—northern and southern red oaks, post oak, white oak, sourwood, shagbark hickory, pignut hickory, yellow-poplar, blackgum, sweetgum, red maple, eastern white pine, pitch pine, Table Mountain pine, shortleaf pine, and Virginia pine. Sites—dry upland sites on thin-soiled rocky outcrops on dry ridges and slopes. Hardwood forest type and member of the oak/hickory forest-type group.

Red maple/oak: Associates—the type is dominated by red maple and some of the wide variety of central hardwood associates include upland oak, hickory, yellow-poplar, black locust, sassafras as well as some central softwoods like Virginia and shortleaf pines. Sites—uplands. Hardwood forest type and member of the oak/hickory forest-type group.

Mixed upland hardwoods: Includes Ohio buckeye, yellow buckeye, Texas buckeye, red buckeye, painted buckeye, American hornbeam, American chestnut, eastern redbud, flowering dogwood, hawthorn spp. (e.g., cockspur hawthorn, downy hawthorn, Washington hawthorn, fleshy hawthorn, and dwarf hawthorn), honeylocust, Kentucky coffeetree, Osage orange, all mulberries, blackgum, sourwood, southern red oak, shingle oak, laurel oak, water oak, live oak, willow oak, black locust, blackbead ebony, anacahuita, and September elm. Associates—any mixture of hardwoods of species typical of the upland central hardwood region, should include at least some oak. Sites—wide variety of upland sites. Hardwood forest type and member of the oak/hickory forest-type group.

Black ash/American elm/red maple (includes slippery and rock elm): Associates—swamp white oak, silver maple, sycamore, pin oak, blackgum, white ash, and cottonwood. Sites—moist to wet areas, swamps, gullies, and poorly drained flats. Hardwood forest type and member of the elm/ash/cottonwood forest-type group.

Cottonwood: Associates—willow, white ash, green ash, and sycamore. Sites—streambanks where bare, moist soil is available. Hardwood forest type and member of the elm/ash/cottonwood foresttype group.

Sugarberry/hackberry/elm/green ash (includes American, winged, cedar, slippery and rock elm): Associates—boxelder, pecan, blackgum, persimmon, honeylocust, red maple, and hackberry. Sites—low ridges and flats in flood plains. Hardwood forest type and member of the elm/ash/cottonwood forest-type group. This type was renamed to green ash/red maple/elm for this report. In Michigan, sugarberry is not part of this type.

Green ash/red maple/elm: See sugarberry/hackberry/elm/green ash. Sugarberry/hackberry/elm/ green ash was renamed to green ash/red maple/elm for this report. In Michigan, sugarberry is not part of this type.

Silver maple/American elm: Silver maple and American elm are the majority species in this type. Associates—chalk maple, sweetgum, pin oak, swamp white oak, eastern cottonwood, sycamore, green ash, and other moist-site hardwoods, according to the region. Sites—primarily on well drained moist sites along river bottoms and floodplains, and beside lakes and larger streams. Hardwood forest type and member of the elm/ash/cottonwood forest-type group.

Red maple/lowland: Red maple comprises a majority of the stocking. Because this type grows on a wide variety of sites over an extensive range, associates are diverse. Associates—yellow-poplar, blackgum, sweetgum, and loblolly pine. Site—generally restricted to very moist to wet sites with poorly drained soils, and on swamp borders. Hardwood forest type and member of the elm/ash/cottonwood forest-type group.

Cottonwood/willow (includes peachleaf, black and Bebb willow): Associates—white ash, green ash, sycamore, American elm, red maple and boxelder. Sites—stream banks where bare, moist soil is available. Hardwood forest type and member of the elm/ash/cottonwood forest-type group.

Sugar maple/beech/yellow birch: Associates—butternut, basswood, red maple, hemlock, northern red oak, white ash, white pine, black cherry, sweet birch, American elm, rock elm, and eastern hophornbeam. Sites—fertile, moist, well drained sites.

Black cherry: Associates—sugar maple, northern red oak, red maple, white ash, basswood, sweet birch butternut, American elm, and hemlock. Sites—fertile, moist, well drained sites. Hardwood forest type and member of the maple/beech/birch forest-type group.

Cherry/ash/yellow-poplar: Associates—sugar maple, American beech, northern red oak, white oak, blackgum, hickory, cucumbertree, and yellow birch. Sites—fertile, moist, well drained sites. Hardwood forest type and member of the oak/hickory forest-type group.

Hard maple/basswood (includes American, Carolina, and white basswood): Associates—black maple, white ash, northern red oak, eastern hophornbeam, American elm, red maple, eastern white pine, eastern hemlock. Sugar maple and basswood occur in different proportions but together comprise the majority of the stocking. Sites—fertile, moist, well drained sites. Hardwood forest type and member of the maple/beech/birch forest-type group.

Elm/ash/locust: Associates—Black locust, silver maple, boxelder, blackbead ebony, American elm, slippery elm, rock elm, red maple, green ash predominate. Found in the Midwest, unknown in the Northeast. Sites—upland. Hardwood forest type and member of the oak/hickory forest-type group.

Red maple/upland: Associates—the type is dominated by red maple and some northern hardwood associates include sugar maple, beech, birch, aspen, as well as some northern softwoods like white pine, red pine, and hemlock; this type is often the result of repeated disturbance or cutting. Sites—uplands. Hardwood forest type and member of the maple/beech/birch forest-type group.

Aspen: Associates—Engelmann spruce, lodgepole pine, ponderosa pine, Douglas-fir, subalpine fir, white fir, white spruce, balsam poplar, and paper birch. Sites—aspen has the capacity to grow on a variety of sites and soils, ranging from shallow stony soils and loamy sands to heavy clays. Hardwood forest type and member of the aspen/birch forest-type group.

Paper birch (includes northern paper birch): Associates—aspen, white spruce, black spruce, and lodgepole pine. Sites—can be found on a range of soils but best developed on well drained sandy loam and silt loam soils. Hardwood forest type and member of the aspen/birch forest-type group.

Balsam poplar: Associates—paper birch, white spruce, black spruce, and tamarack. Sites—occurs on rich floodplains where erosion and folding are active. Hardwood forest type and member of the aspen/birch forest-type group.

Appendix 4. Live Tree Volume by Species and Forest Type

Distribution of live tree volume (trees at least 5 inches d.b.h.) on forest land by species and forest type, Michigan, 2014, in thousand cubic feet (30 most common species by live tree volume for select forest types accounting for 72 percent of forest land acreage).

Species	Total	Sugar maple/ beech/yellow birch	Other forest types	Aspen	White oak/ red oak/ hickory	Hard maple /basswood	Northern white-cedar	Red pine	Red maple/ upland	Northern red oak	Black ash/ American elm/ red maple	Eastern white pine	Red maple/ lowland	Green ash/ red maple/ elm
Sugar maple	5,042,548	3,108,870	74,248	72,763	32,768	1,593,158	3,938	11,892	96,950	29,179	5,873	3,672	2,954	6,283
Red maple	4,738,799	1,335,577	788,909	297,841	391,676	53,979	82,746	26,783	811,936	102,373	159,715	25,512	544,173	117,579
Northern white-cedar	2,898,831	188,546	224,321	186,963	7,454	24,615	2,031,537	5,179	6,141	6,157	155,333	8,757	31,157	22,670
Red pine	2,401,970	26,575	346,679	29,541	34,937	729	298	1,843,385	3,509	26,630	0	87,603	1,965	119
Eastern white pine	1,743,774	88,662	523,840	108,972	116,911	8,281	81,243	108,171	29,152	33,759	10,145	618,109	9,965	6,564
Northern red oak	1,729,205	252,009	183,339	90,931	330,371	77,955	644	5,980	6,252	769,223	3,031	4,277	378	4,815
Quaking aspen	1,625,273	151,832	183,502	1,035,796	25,870	30,023	37,536	21,173	30,902	10,170	24,973	21,629	11,343	40,524
Bigtooth aspen	1,274,772	148,189	126,566	724,229	137,700	41,282	304	20,435	14,360	51,789	1,984	3,414	1,471	3,048
Black cherry	1,098,206	208,841	483,466	41,812	150,514	67,684	733	14,021	38,124	9,182	12,513	35,398	16,580	19,338
Eastern hemlock	1,080,275	572,163	309,885	12,628	3,387	35,141	40,810	1,143	59,819	5,378	14,609	6,541	18,203	565
American basswood	850,154	124,327	42,821	12,035	78,163	526,092	2,287	0	4,917	7,559	29,632	205	4,598	17,518
White oak	808,510	5,354	329,878	13,058	388,827	1,228	0	10,904	53	51,248	1,827	3,887	22	2,225
Black oak	805,153	2,737	159,116	2,494	595,024	259	0	16,289	0	12,708	0	2,774	13,751	0
Balsam fir	703,093	136,619	181,341	149,680	5,789	16,645	104,264	4,144	37,905	920	31,035	10,302	19,058	5,392
Silver maple	657,968	9,329	395,167	7,102	2,889	4,114	709	0	680	0	168,960	0	36,539	32,479
White spruce	655,876	108,718	262,938	102,749	1,009	19,464	77,699	17,475	20,107	636	19,586	14,732	9,199	1,563
Yellow birch	633,324	476,814	37,229	8,446	729	17,595	21,384	0	22,612	550	36,057	326	6,834	4,749
Paper birch	606,695	106,603	230,467	79,606	12,789	23,070	86,256	4,969	15,084	3,124	13,717	11,351	9,183	10,475
Green ash	565,075	13,902	117,036	24,912	14,655	2,057	6,322	798	1,370	420	65,142	933	19,361	298,168
American beech	557,500	443,315	20,155	6,130	16,723	19,443	55	678	20,909	25,328	618	1,354	927	1,865
Jack pine	453,877	3,479	390,829	2,471	12,201	160	0	31,600	3,359	1,446	0	8,129	0	203
Black spruce	444,648	7,856	300,263	11,289	834	195	96,695	4,310	4,030	166	4,903	8,826	4,391	889
White ash	432,236	97,453	33,112	15,511	29,042	198,470	1,309	789	334	25,711	10,422	533	3,701	15,848
Black ash	322,721	58,005	29,412	6,804	288	18,351	36,890	0	1,661	398	149,486	49	10,676	10,701
Northern pin oak	299,924	78	68,625	12,018	185,051	779	0	21,352	0	3,606	89	3,351	3,238	1,737
Eastern cottonwood	288,109	11,146	225,015	1,043	12,644	2,653	0	0	0	0	15,555	0	2,605	17,447
Tamarack (native)	235,289	550	151,255	5,691	71	53	62,048	2,695	0	0	9,182	1,163	2,582	0
American elm	229,311	30,167	86,409	7,236	23,933	6,439	922	0	194	1,312	19,804	1,631	19,853	31,412
Scotch pine	213,407	1,493	184,688	1,106	6,561	0	0	7,908	0	0	2,446	4,313	1,199	3,692
Balsam poplar	204,143	2,468	102,552	42,818	0	807	38,539	1,211	807	0	9,309	385	164	5,084
Top 30 species	33,600,663	7,721,675	6,593,063	3,113,676	2,618,809	2,790,723	2,815,167	2,183,286	1,231,169	1,178,972	975,946	889,154	806,071	682,954
All Species	34,802,286	7,817,062	7,082,216	3,137,269	2,953,138	2,848,839	2,815,665	2,187,493	1,232,900	1,182,776	1,046,282	890,186	819,989	788,473

Appendix 5. Updated Net Growth Ratio Estimates

Comparison of updated versus previously published ratio estimates (Pugh et al. 2012) of average annual net growth to current volume (percent) and average annual net growth to average annual harvest removals for growing stock on timberland-to-timberland observations, Michigan 2009.

Estimate type	Updated net growth to current volume	Previous net growth to current volume	Updated net growth to harvest removals	Previous net growth to harvest removals
	---------------- *percent*	----------------	------------------- *ratio*	-------------------
MI total	2.1	2.5	1.9	2.4
MN total	1.9	2.8	1.2	1.9
WI total	2.3	2.9	1.7	2.0
MI eastern Upper Peninsula	1.7	2.1	1.4	1.7
MI western Upper Peninsula	1.6	1.7	1.3	1.4
MI northern Lower Peninsula	2.5	2.9	2.4	2.8
MI southern Lower Peninsula	2.4	3.3	3.2	4.6
MI private ownership	2.3	2.7	1.8	2.2
MI State and local government ownership	2.0	2.3	1.8	2.2
MI U.S. Forest Service ownership	1.7	1.8	5.0	5.0

Appendix 6. Insects and Diseases

The following is a list of insects and diseases mentioned in this report, Michigan, 2014. It is not a complete list of insects and diseases and includes species that have not been detected in Michigan.

Armillaria root rot	*Armillaria spp.*
Ash yellows	*Mycoplasmalike organisms* et al.
Asian longhorned beetle	*Anoplophora glabripennis*
Aspen leafblotch miner	*Phyllonorycter apparella*
Balsam woolly adelgid	*Adelges piceae*
Beech bark disease	*Cryptococcus fagisuga and Nectria*
Beech scale	*Cryptococcus fagisuga*
Bronze birch borer	*Agrilus anxius*
Butternut canker	*Sirococcus clavigignenti-juglandacearum*
Chestnut blight	*Cryphonectria parasitica*
Diplodia blight	*Diplodia pinea*
Diplodia in white pine decline	*Diplodia scrobiculata*
Dutch elm disease	*Ophiostoma ulm and bark beetles*
Eastern larch beetle	*Dendroctonus simplex*
Emerald ash borer	*Agrilus planipennis*
Fall cankerworm	*Alsophila pometaria*
Fall webworm	*Hyphantria cunea*
Forest tent caterpillar	*Malacosoma disstria*
Gypsy moth	*Lymantria dispar*
Hemlock wooly adelgid	*Adelges tsugae*
Heterobasidion root disease	*Heterobasidion irregularae*
Hickory wilt	*Scolytus quadrispinosus* and *Ceratocystis smalleyii*
Hypoxylon canker	*Hypoxylon mammatum*
Jack pine budworm	*Choristoneura pinus*
Larch casebearer	*Coleophora laricella*
Large aspen tortrix	*Choristoneura conflictana*
Linden looper	*Erranis tiliaria*
Oak wilt	*Ceratocystis fagacearum*
Orange-humped mapleworm	*Symmerista leucitys*
Pine spittlebug	*Diplodia scrobiculata*
Septoria leaf spot	*Setoria musiva*
Sirex wooodwasp	*Sirex noctilio*
Spruce budworm	*Choristoneura fumiferana*
Spruce needle rust	*Chrysomyxa ledicola*
Sudden oak death or ramorum blight	*Phytophthora ramorum*
Thousand cankers disease	*Pityophthorus juglandis* and *Geosmithia morbida*
Therrya spp. in white pine decline	*Therrya* spp.
Two-lined chestnut borer	*Agrilus bilineatus*
White pine weevil	*Pissodes strobi*

Appendix 7. Invasive Plant Species

The following is a list of invasive plant species monitored on P2 plots, Michigan, 2014. An asterisk indicates species found in the inventory.

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

Pugh, Scott A.; Heym, Douglas C.; Butler, Brett J.; Haugen, David E.; Kurtz, Cassandra M.; McWilliams, William H.; Miles, Patrick D.; Morin, Randall S.; Nelson, Mark D.; Riemann, Rachel I.; Smith, James E.; Westfall, James A.; Woodall, Christopher W. 2017. **Michigan forests 2014.** Resour. Bull. NRS-110. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 154 p.

The eighth inventory of Michigan's forests, completed in 2014, describes more than 20.3 million acres of forest land. The data in this report are based on visits to 4,289 forested plots from 2009 to 2014. Timberland accounts for 95 percent of this forest land, and 62 percent is privately owned. The sugar maple/beech/yellow birch forest type accounts for 19 percent of the State's forest land, followed by aspen (12 percent) and white oak/red oak/hickory (7 percent). Balsam fir, red maple, and sugar maple are the three most common species by number of trees. Growing-stock volume on timberland has continued to increase and now totals about 30.2 billion cubic feet (ft^3). The associated net growth, harvest removals, and mortality totaled 674, 313, and 303 million ft^3/year, respectively. In addition to information on forest attributes, this report includes data on forest health, land use change, family forest owners, timber-product outputs, and future forests. Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found online at https://doi.org/10.2737/NRS-RB-110.

KEY WORDS: inventory, carbon, forest area, timberland, forest land, sustainability, volume, mortality, harvest, growth, forest health, land use change

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