USDA

United States Department of Agriculture

Minnesota Forests 2013

Forest Service

Northern Research Station

Resource Bulletin NRS-104

Publication Date August 2016

Abstract

The third full annual inventory of Minnesota forests reports 17.4 million acres of forest land with an average live tree volume of 1,096 cubic feet per acre. Forest land is dominated by the aspen forest type, which occupies 29 percent of the total forest land area. Twenty-eight percent of forest land consists of sawtimber, 35 percent poletimber, 36 percent sapling/seedlings, and 1 percent is nonstocked. The average annual net growth of live trees on forest land is approximately 398 million cubic feet per year while average annual removals are only 207 million cubic feet per year. Additional forest attribute and forest health information is presented, along with information on agents of change including changing land use patterns and the introduction of nonnative plants, insects, and disease. Information from the Private Woodland Owner and Timber Products Output surveys is included along with 50-year projections from the Northern Forest Futures study. Detailed information on forest inventory methods, data quality estimates, and important resource statistics are available online at http://dx.doi.org/10.2737/NRS-RB-104.

Acknowledgments

The authors would like to thank those who contributed both to the inventory and analysis of Minnesota forest resources. Data management personnel included James Blehm, Mark Hatfield, Dan Kaisershot, Barb O'Connell, Jay Solomakos, Paul Sowers, and Jeff Wazenegger. Field crew and QA staff over the 2009-2013 field inventory cycle included:

Sue Abrahamsen
Joshua Anderson
Micah Anderson
Steve Aysta
John Benaszeski
Kristen Bergstrand
Thom Bergstrom
James Blehm
Patrick Churack
Brian Clennon
Dennis Collson
Shawn Conrad
Gary Cummings
Albert Dietz
Michael Downs
Steve Flackey
Joshua Garner
Brian Giersdorf
Bruce Giersdorf
Stan Grossman
Tim Halberg
Brandon Hanko
Jered Hayes
Larry Hoyt
Dan Huberty
Brent Hummel
Chandler Johnson
Dan Kaisershot
Dennis Kepler
Peter Koehler
Troy Korpi
Tim Koski
Cassandra Kurtz
Rebecca Landewe
Mark Majewsky
Kelly Meier
Bobby Morris
Trent Murphy
Sheldon Murphy
Rachael Nicoll
Grant Nielsen
Benjamin Nurre
Cassandra Olson
Melissa Powers
Mike Rosha
Dave Roth
Sjana Schanning
Heidi Schmidt
Jonathan Stelter
Matt Swanson
Leland Swoger
Brad Totten
Josh Trautner
Brian Wall
Brittany Wedgewood
Bryan Wilfong
Derek Wilkerson
Dan Woitalla

Cover: Brown's Lake near Ely, MN. Photo by Eli Sagor, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

Manuscript received for publication July 2015

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

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

August 2016

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

Printed on recycled paper

Minnesota Forests, 2013

Patrick D. Miles, Curtis L. VanderSchaaf, Charles Barnett, Brett J. Butler, Susan J. Crocker, Dale Gormanson, Cassandra M. Kurtz, Tonya W. Lister, William H. McWilliams, Randall S. Morin, Mark D. Nelson, Charles H. Perry, Rachel I. Riemann, James E. Smith, Brian F. Walters, James A. Westfall, Christopher W. Woodall

Contact Author:
Patrick Miles
pmiles@fs.fed.us
651-649-5146

About the Authors

Patrick D. Miles, Susan J. Crocker, Mark D. Nelson, and Christopher W. Woodall are research foresters with the Forest Inventory and Analysis (FIA) Program, Northern Research Station, St. Paul, MN.

Curtis L. VanderSchaaf, formerly a forest analyst for the Forestry Resource Assessment Program, Minnesota Department of Natural Resources, Grand Rapids, MN, is currently at Louisiana Tech University in Ruston, LA.

Charles Barnett is a biological scientist with the FIA program, Northern Research Station, Newtown Square, PA.

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

Dale Gormanson, Cassandra M. Kurtz, and Brian F. Walters are foresters with the FIA program, Northern Research Station, St. Paul, MN.

Tonya W. Lister, William H. McWilliams, Randall S. Morin, and James A. Westfall are research foresters with the FIA program, Northern Research Station, Newtown Square, PA.

Charles H. Perry is a research soil scientist with the FIA program, Northern Research Station, St. Paul, MN.

Rachel I. Riemann is a research forester/geographer with the FIA program, Northern Research Station, Troy, NY.

James E. Smith is a research forester with the FIA program, Northern Research Station, Durham, NH.

Foreword

Minnesota is home to three major ecosystems: prairies in the west, sub-boreal forests in the northeast, and hardwoods running between the two from the Canadian border to the southeastern area of the State. As a result, the forests of Minnesota are many and varied. In this report the authors will highlight the current status, ongoing trends, and future direction of the State's forests.

Change in the early years of the 21st century pales in comparison to the dramatic changes of the late 1800s and early 1900s. During that period nearly half of Minnesota forest land was converted to agriculture and other land uses in the wake of widespread lumbering that peaked in 1905 (Waters 1977). Since then, the State's forests have been a remarkable story of resiliency and recovery. However, demands on forest resources will continue to increase along with biological threats from nonnative plants and insects. Minnesotans face the challenge of managing forests in such a way that they are available for use and enjoyment in the future as well as today.

The ability to report on trends in the condition and status of forest resources is critical to knowing whether resources are being used or maintained in a sustainable way. The U.S. Department of Agriculture, Forest Service, through its Forest Inventory and Analysis program and in partnership with the Minnesota Department of Natural Resources, Division of Forestry, inventoried Minnesota forest resources in 1935, 1953, 1962, 1977, 1990, 2003, 2008, and 2013. Starting in 1999, annual inventories have been conducted in which a portion of field plots is inventoried each year and a full inventory is completed after 5 years. The first Minnesota annual inventory was completed in 2003 and covers 1999 to 2003. The second annual inventory was completed in 2008 and covers the period from 2004 to 2008. The third annual inventory was completed in 2013 and covers the period from 2009 to 2013. With three complete sets of remeasurement data from annual inventory plots, we are able to produce better estimates of growth, mortality, and removal trends and to produce detailed reports on ground land-use change.

This report provides an overview of the current condition and health of Minnesota forests. We hope the information provided will stimulate discussion about the State's forest resources and spur further research and analysis to help improve and maintain the productivity, health, and vigor of Minnesota forests.

Contents

Highlights 1

Background 3

Forest Features 13

Health Indicators 59

Socioeconomics 107

Literature Cited 119

Appendixes 131

Statistics, Methods, and Quality Assurance and Glossary . . . .
Online at http://dx.doi.org/10.2737/NRS-RB-104

Minnesota Forests Summary Tables . . . .
Online at http://dx.doi.org/10.2737/NRS-RB-104

Additional Resources……Online at http://dx.doi.org/10.2737/NRS-RB-104

Highlights

On the Plus Side

- Minnesota ranks 14th among the 50 states in land area, 20th in forest land, 15th in area of Federal forest land, and 1st in area of state/county/local government forest land.
- Forest land accounts for 17.4 million acres or 34 percent of the land area in Minnesota. Most of Minnesota forest land (90 percent or 15.7 million acres) is timberland.
- The area of forest land increased from 17.0 million acres in 2008 to 17.4 million acres in 2013. Half of the forest gains came from marshes and bogs.
- The total oven-dry biomass of all live trees on forest land increased from 438 million tons in 2003 to 458 million tons in 2008 to 484 million tons in 2013.
- Average annual net growth of growing stock on timberland for the 2013 inventory was 375 million cubic feet or roughly 2.5 percent of the total growing-stock volume in 2013, a slight decrease from the 384 million average annual net growth reported in the 2008 inventory.
- Average annual removals of growing stock on timberland for the 2013 inventory was 178 million cubic feet, or roughly 1.6 percent of the total growing-stock volume in 2013, a significant decrease from the 276 million cubic feet of average annual removals reported in the 2008 inventory.
- A growth-to-removals ratio of 1.7 for growing-stock trees on lands that were timberland at the time of both the current and previous inventories indicates that net growth is 1.7 times greater than removals and that growing-stock volume is increasing.
- In Minnesota for every 100 live trees more than 5 inches in diameter on forest land there are 13.7 standing dead trees that provide valuable wildlife habitat.
- Over 40 thousand people are directly employed in the forest products manufacturing and related sectors of the economy. The forest products industry is the fifth largest manufacturing sector in Minnesota.

Opposite: Fall foliage at Kettle River Scientific and Natural Area, Minnesota. Photo by Justin Meissen, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

Issues to watch

- Approximately 44 percent of the forest land in Minnesota is less than fully stocked: 32 percent of forest land has medium stocking, 11 percent is poorly stocked, and 1 percent is nonstocked.
- Nearly 73 percent of hardwood sawtimber on timberland is in lower valued trees (grades 3 or lower), 21 percent is in tree grade 2, and 6 percent is in tree grade 1.
- The average annual mortality of growing stock on timberland from 2009 to 2013 was 237 million cubic feet, an amount equal to 1.6 percent of the total growing-stock volume on timberland in 2013. This rate is slightly lower than the 1.7 percent reported in 2008 and the 1.8 percent reported in 2003.
- High mortality rates have led to a 9 percent decline in the live volume of paper birch on forest land, a 7 percent decline in the volume of jack pine, and a 5 percent decline in the volume of balsam poplar and eastern cottonwood.
- European gypsy moth egg masses have been discovered in several locations in Lake and Cook counties. The Minnesota Department of Agriculture enacted a quarantine on July 1, 2014 to restrict movement of potentially infected items from these counties.
- The emerald ash borer, which threatens all species of ash, has established itself in the Minneapolis-Saint Paul metro area and in the southeastern corner of the State.
- Of the 40 invasive plant species monitored, reed canarygrass was the most commonly observed (18 percent of Phase 2 invasive plots). Nonnative bush honeysuckles and common buckthorn were the next most commonly observed invasive species and occurred on more than 10 percent of forested plots.
- Fragmentation and parcelization of the forest are increasing in Minnesota. Forest fragmentation occurs when a contiguous forest area is divided into smaller blocks, usually through the construction of roads and housing, clearing for agriculture, or other human development. Parcelization occurs when large holdings of one owner are broken up into smaller acreages held by multiple owners.

Background

Nerstrand Big Woods State Park, Minnesota. Photo by Eli Sagor, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

An Overview of Forest Inventory

What is FIA?

The Forest Inventory and Analysis program, commonly referred to as FIA, is the nation's forest census. It was established by the U.S. Congress to "make and keep current a comprehensive inventory and analysis of the present and prospective conditions of and requirements of the forest and range lands of the United States" (Forest and Rangeland Renewable Resources Planning Act of 1974; 16 USC 1601 note). FIA has been collecting, analyzing, and reporting on the nation's forest resources for over 80 years with the first FIA inventory of Minnesota forests completed in 1935. Information is collected on the status and trends of the extent, composition, structure, health, and ownership of the forests. This information is used by policy makers, resource managers, researchers, and the general public to better understand forest resources and to make more informed decisions about the fate of the forests.

What is this report?

This report is a summary of the findings from the eighth survey of the forest resources of Minnesota conducted by FIA. Data for this survey were collected between 2009 and 2013, but throughout this report, we refer to 2013 as the inventory year.

The results of the survey are divided into chapters that focus on forest features, health indicators, and socioeconomics. Details about the data collection, estimation procedures, and statistical reliability are included in the section "Statistics, Methods, and Quality Assurance," at http://dx.doi.org/10.2737/NRS-RB-104. The Web site also includes a glossary of terms and numerous tables summarizing the results reported here.

Maps in this report were constructed using (1) categorical coloring of Minnesota counties according to forest attributes (such as forest land area), (2) a variation of the k-nearest neighbor (kNN) technique to apply information from forest inventory plots to remotely sensed MODIS imagery (250-m pixel size) based on the spectral characterization of pixels and additional geospatial information, or (3) colored dots to represent plot attributes at approximate plot locations.

A Guide to Forest Inventory

What is a tree?

We know a tree when we see one and we can agree on some common tree attributes. Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. In Minnesota the problem is in deciding which species should be classified as shrubs and which should be classified as trees. A complete list of the tree species measured in this inventory can be found in Appendix 1 at the end of this printed document.

What is a forest?

We all know what a forest is, but where does the forest stop and the prairie begin? It's an important question. The gross area of forest land or rangeland may determine the allocation of funding for certain State and Federal programs. Forest managers want more land classified as forest land, range managers want more land classified as prairie. Somewhere you have to draw the line.

FIA defines forest land as land that has at least 10 percent canopy cover by live trees or had at least 10 percent canopy cover by live trees in the past, based on the presence of stumps, snags, or other evidence, and is not currently developed for nonforest use. The area with trees must be at least 1 acre in size, and roadside, streamside, and shelterbelt strips must be at least 120 feet wide to qualify as forest land.

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

From an FIA perspective, there are three types of forest land: timberland, reserved forest land, and other forest land. In Minnesota, 90 percent of the forest land is timberland, 7 percent is reserved forest land, and 3 percent is other forest land.

- Timberland is unreserved forest land that meets the minimum productivity requirement of 20 cubic feet per acre per year at its peak.
- Reserved forest land is land that is withdrawn from timber utilization (i.e., trees are not cut for the purpose of timber utilization) through legislation or administrative regulation. In Minnesota, most of the reserved forest land is in the Boundary Waters Canoe Area Wilderness and Voyagers National Park.

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

Prior to 1999 only trees on timberland plots were measured in Minnesota. Therefore, volume on timberland can be reported for those inventories, but volume on forest land cannot be reported. Under the annual inventory system (in Minnesota the annual inventory system was implemented in 1999), trees were measured on all forest land, and therefore forest volume estimates can be produced. Annual plots were remeasured in 2008 and again in 2013, making it possible to report growth, removals, and mortality on all forest land for two points in time using annual inventory plots.

How many trees are in Minnesota?

There are approximately 2.4 billion trees on Minnesota forest land (give or take a few million) that have a diameter at breast height (d.b.h.; diameter measured at 4.5 feet above the ground) of at least 5 inches. The exact number is not known because only about 1 out of every 18,000 trees is measured[1]. In all, 125,611 trees with a d.b.h. of 5 inches and larger were sampled on 6,221 forested plots during the 5 years from 2009 to 2013.

How do we estimate a tree's volume?

FIA typically expresses volumes in cubic feet, but in Minnesota wood is more commonly measured in cords (a stack of logs 8 feet long by 4 feet wide and 4 feet high). A cord has approximately 79 cubic feet of solid wood and 49 cubic feet of bark and air.

Volume can be precisely determined by immersing a tree in a pool of water and measuring the amount of water displaced. Less precise, but much cheaper, was the method used by the North Central Research Station (which later merged with the Northeastern Research Station to become the Northern Research Station). Several hundred cut trees were measured by taking detailed diameter measurements along their lengths to accurately determine their volumes (Hahn 1984). Regression lines were then fit to this data by species group. Using these regression equations, individual tree volume estimates based on species, diameter, and tree site index can be produced.

The same method was used to determine sawtimber volumes. FIA reports sawtimber volumes in International ¼-inch board foot scale. Conversion factors for converting to Scribner board foot scale are also available (Smith 1991).

---

[1] During the 2013 inventory of Minnesota one 1/6th-acre plot was measured for approximately every 3,000 acres of forest land.

How much does a tree weigh?

The U.S. Forest Service Forest Products Laboratory and others developed specific gravity estimates for a number of tree species (Miles and Smith 2009). These specific gravities were then applied to tree volume estimates (Hahn 1984) to derive estimates of merchantable tree biomass (the weight of the bole). To estimate live biomass, stump, limb, and bark biomass were added (Heath et al. 2009). The live biomass of roots or foliage is currently not reported.

Forest inventories report biomass as green or oven-dry weight. Green weight is the weight of a freshly cut tree; oven-dry weight is the weight of a tree with zero percent moisture content. On average, 1 ton of oven-dry biomass is equal to 1.9 tons of green biomass.

How do we estimate all the forest carbon pools?

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

How do we compare data from different inventories?

Data from new inventories are often compared with data from earlier inventories to determine trends in forest resources. This is certainly valid when comparing the 2008 inventory to the 2013 inventory and even the 2003 inventory to the 2008 inventory. But comparisons with inventories conducted before 1999 are problematic because procedures for assigning stand characteristics like forest type and stand size have changed as a result of FIA's ongoing efforts to improve the efficiency and reliability of the inventory. Several changes in procedures and definitions have occurred since the 1990 Minnesota periodic inventory. Although these changes will have little impact on statewide estimates of forest area, timber volume, and tree biomass, they may have significant impacts on estimates based on forest type and stand-size class. Some of these changes make it inappropriate to directly compare the 2013, 2008, and 2003 annual inventory tables with periodic inventories published for 1935, 1953, 1962, 1977, and 1990.

A major difference between periodic and annual inventories is the change in plot design. In an effort toward national consistency, a single national plot design was implemented by all five regional FIA units in 1999. The old North Central plot design used in the 1990 Minnesota inventory consisted of variable-radius subplots. The new national plot design used in the 2003, 2008, and 2013 inventories uses fixed-radius subplots. Both designs have their strong points, but they often produce different classifications for individual plot characteristics.

The 1990 inventory also used modeled plots that were measured in 1977 and projected forward using the STEMS growth model (Belcher et al. 1982). This was done to save money by reducing the number of undisturbed plots that were remeasured, where disturbance was determined by examining aerial photographs of the plots. The idea was that parameters for the STEMS growth model could be fine-tuned using the measured undisturbed plots and then be applied to the remaining unmeasured undisturbed plots. Unfortunately, the use of modeled plots appears to have resulted in the overestimate of the 1990 live tree volume on timberland by about 6 percent.

Reserve status—improved implementation

FIA defines reserved forest land as forest land withdrawn by law(s) prohibiting the management of land for the production of wood products (not merely controlling or prohibiting wood-harvesting methods). All private productive forest land, regardless of conservation easements that may restrict harvesting, is declared timberland. Timberland does not include reserved forest land.

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 year. Furthermore, all previously collected annual inventory data (1999 to present) have been updated using the new standardized interpretation. 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.

The 2012 inventory is the last inventory in which all data are available under both the previous and improved reserve class implementations (Table 1). Small but significant changes are associated with estimates of timberland acreage, number of trees, volume, and biomass. The large decrease in the estimate of annual other removals of growing stock is the result of a more consistent determination of reserved status across inventories (i.e., less land was classified as timberland last inventory and then classified as reserved forest land this inventory).

Table 1.—Impact on timberland estimates resulting from refined procedures for determining reserved status, Minnesota, 2012

Timberland	2012 estimate previous	2012 estimate improved	Difference	Difference (percent)
Area (thousand acres)	15,990	15,696	294	-2
Number of live trees ≥1 inch diameter (million trees)	12,809	12,613	196	-2
Aboveground biomass of live trees ≥1 inch (thousand oven-dry tons)	447,430	437,366	10,064	-2
Net volume of live trees (million ft^3)	17,501	17,094	407	-2
Net volume of growing-stock trees (million ft^3)	15,005	14,656	349	-2
Annual net growth of growing-stock trees (thousand ft^3/yr)	370,209	363,274	6,956	-2
Annual mortality of growing-stock trees (thousand ft^3/yr)	252,743	245,437	7,306	-3
Annual harvest removals of growing-stock trees (thousand ft^3/yr)	186,467	186,023	444	0
Annual other removals of growing-stock trees (thousand ft^3/yr)	28,025	8,731	19,294	-69

A word of caution on suitability and availability

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

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 and objectives. While change is inevitable, we hope that through clarity and transparency forest inventory data will be of use to analysts for decades to come.

Major Components of the FIA Program

Forest Inventory

Information on the condition and status of forests in Minnesota was obtained from the Northern Research Station's Forest Inventory and Analysis (NRS-FIA) program. Previous inventories of the State's forest resources were completed in 1935, 1953, 1962, 1977, 1990, 2003, and 2008 (Zon 1935, Cunningham et al. 1958, Stone 1966, Jakes 1980, Leatherberry et al. 1995, Miles et al. 2007, Miles et al. 2011, respectively).

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

With the NRS-FIA annual inventory system, approximately one-fifth of all field plots are measured in Minnesota each year. The entire inventory is completed every 5 years. NRS-FIA reports and analyzes results using a moving 5-year average. For example, NRS-FIA generates inventory results for 1999 through 2003, 2004 through 2008, or 2009 through 2013.

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

Identical classification procedures were used to assign forest type and stand-size class for the 2003, 2008, and 2013 annual inventories, so comparisons between these inventories are relatively simple. Comparisons with earlier inventories (1990, 1977, 1962, 1953, and 1935) are more problematic due to the changes in plot design and data-collection classification methods. Contact NRS-FIA for additional information on the algorithms used in various inventories.

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

National Woodland Owner Survey

Information about family forest owners is collected annually through the U.S. Forest Service's National Woodland Owner Survey (NWOS). The NWOS was designed to increase our understanding of owner demographics and motivation. Individuals and private groups identified as woodland owners by FIA are invited to participate in the NWOS. Each year, questionnaires are mailed to 20 percent of private owners; more detailed questionnaires are sent out in years that end in 2 or 7 to coincide with national census, inventory, and assessment programs. Data presented here are based on survey responses from randomly selected families and individuals who own forest land in Minnesota. For additional information about the NWOS, visit: www.fia.fs.fed.us/nwos.

Timber Products Output Inventory

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

Forest Features

Chengwatana State Forest, Minnesota. Photo by Justin Meissen, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

Forest Area

Background

Area estimates are the most basic, most easily understood, and most frequently cited of all forest inventory estimates. They are essential in assessing the status and trends of Minnesota forest ecosystems. Fluctuations in the forest land base may indicate land use trends and changing forest health conditions. Area estimates are reported in acres (640 acres equal 1 square mile).

What we found

Minnesota forest land area is currently estimated at 17.4 million acres or a little more than one-third of the land area of the State (Fig. 1). The presettlement area of forest land was estimated to be 31.5 million acres (Marschner 1930). The largest decline in the area of forest land occurred before the first forest inventory was conducted in the mid-1930s and was due to lumbering followed by homesteading and land clearing (Zon 1935). This decline continued through the first four inventories of Minnesota. By 1977, the area of forest land was estimated at 16.5 million acres and has remained relatively stable, with a slight increase in 1990, followed by a slight decrease in 2003, a 5 percent increase in 2008, and a further increase of 2 percent in 2013. The slight decrease in reported forest area from 1990 to 2003 may be due to the change in plot design.

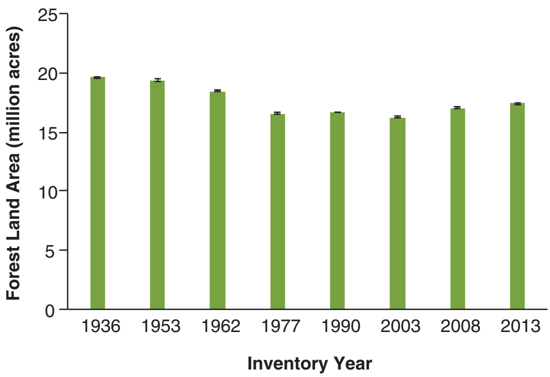


Figure 1.—Area of forest land by inventory year, Minnesota. Error bars represent a 68 percent confidence interval around the estimated mean.

In Minnesota, forest land is concentrated in the northeastern and southeastern counties (Fig. 2). Changes in the area of forest land vary by region. Eighty-eight percent of Minnesota forest land lies above the 46th parallel which runs through the town of Hinckley, MN (Fig. 3). Above this line, the area of forest land increased from 14.6 million acres in 2003 to 15.0 million in 2008 and 15.3 million acres in 2013, a 5 percent increase over the decade. Below this line the area of forest land increased from 1.6 million in 2003 to 1.9 million in 2008 and 2.1 million in 2013, a 26 percent decadal increase. A more comprehensive examination of land-use change is provided in the Land-use Change section of this report.

Overall, Minnesota is 34 percent forest land, which is low for the Lake States but average for the United States (Table 2). Minnesota ranks 14th among the 50 states in land area, 18th in forest land, and 15th in area of timberland.

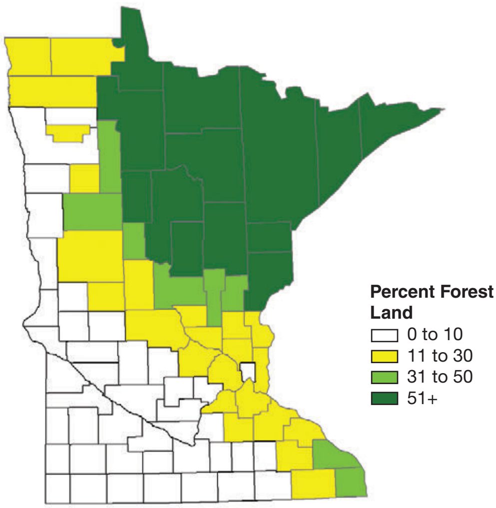


Figure 2.—Percentage of forested land by county, Minnesota, 2013.

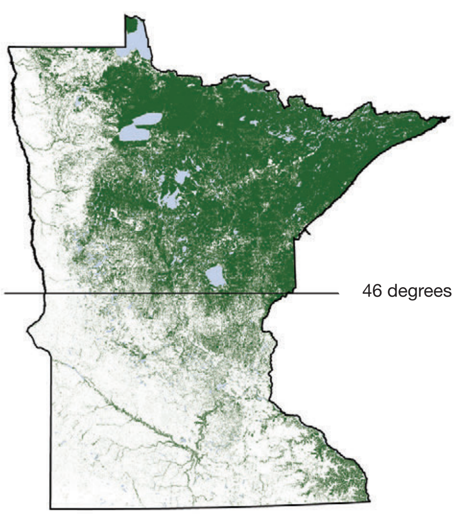


Figure 3.—Forest area from National Land Cover Dataset (Homer et al. 2007).

Table 2.—Minnesota in context: Area of forest land

Geographic area	Percent forest land
World (FAO 2010)	31
North America (FAO 2010)	33
United States (Oswalt et al. 2014)	34
Lake States (MN, MI, WI 2013)	45
Minnesota (2013)	34

Approximately 90 percent of Minnesota forest land is classified as timberland. The area of timberland was estimated at 14.5 million acres in 2003 and increased to 15.3 million acres in 2008, and then to 15.7 million acres in 2013. Additional information on forest land dynamics is provided in the Land-use Change section.

What this means

The area and extent of Minnesota forests decreased from the first forest inventory in 1935 through the fourth inventory in 1977. The slight increase in forest land area from 1977 to 1990 was due in part to the Federal Conservation Reserve Program (Food Security Act of 1985 [P.L. 99-198, 1985 farm bill]). Under this program, erosion-prone cropland was removed from crop production and often reverted to forest land. The increase in forest land from 2003 to 2008 was due primarily to reversion of marsh and agricultural lands to forest land.

Approximately 16.6 million acres of forest land that was forested in 2008 remained forest land in 2013. An estimated 748 thousand acres of land that was not forested in 2008 reverted to forest land by 2013 while only 295 thousand acres diverted from forest to nonforest. The net result of these diversions and reversions was a 2.3 percent increase in the area of forest land from 2008 to 2013.

Increases in the area of timberland between the 1977 and 1990 periodic inventories were due in part to changing site productivity estimates. The area of other forest land declined from 1.9 million acres in 1977 to 840 thousand acres in 1990, with nearly half of this acreage decrease due to conversion to nonforest land and the other half due to conversion to timberland. Since the implementation of the annual inventory system in 1999, the estimate of other forest land has declined from 501 thousand acres in 2003, to 478 thousand acres in 2008, and finally to 444 thousand acres in 2013. Using current site productivity estimates, it is likely that three quarters of a million acres classified as other forest land in 1977 would be classified as timberland today.

Forest Type Distribution

Background

Minnesota is at the confluence of three ecoregion provinces (Bailey 1980), the Laurentian Mixed Forest Province in the northeast, the Eastern Broadleaf Forest Province through the center and southeastern section of the State, and the Prairie Parkland Province in the west (Fig. 4). These provinces, largely determined by geology and climate, are closely linked to forest type distributions within Minnesota.

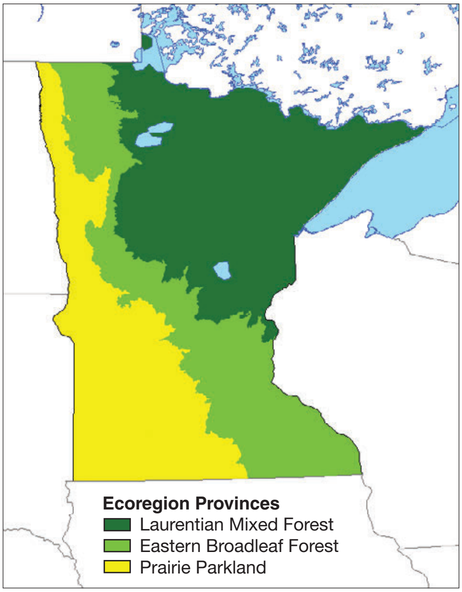


Figure 4.—Bailey's ecoregion provinces of Minnesota.

What we found

Information from forest inventory plots was combined with Modis imagery to produce a forest type map. This technique, a variation of the k-nearest neighbor (kNN) approach, applied information from forest inventory plots to remotely sensed Modis imagery based on the spectral characterization of pixels and additional geospatial information (Wilson et al. 2012). The result was a continuous map where aspen/birch, white/red/jack pine, and spruce/fir forest-type groups predominate in the north while the oak/hickory and elm/ash/cottonwood forest-type groups predominate in the south (Fig. 5).

Aspen is the most abundant cover type in Minnesota (see Appendix 2 for Minnesota DNR cover types), accounting for 29 percent of Minnesota forest land (5.0 million acres) (Fig. 6) followed by northern hardwoods (9 percent), black spruce (9 percent), oak (9 percent), and lowland hardwoods (9 percent) forest types.

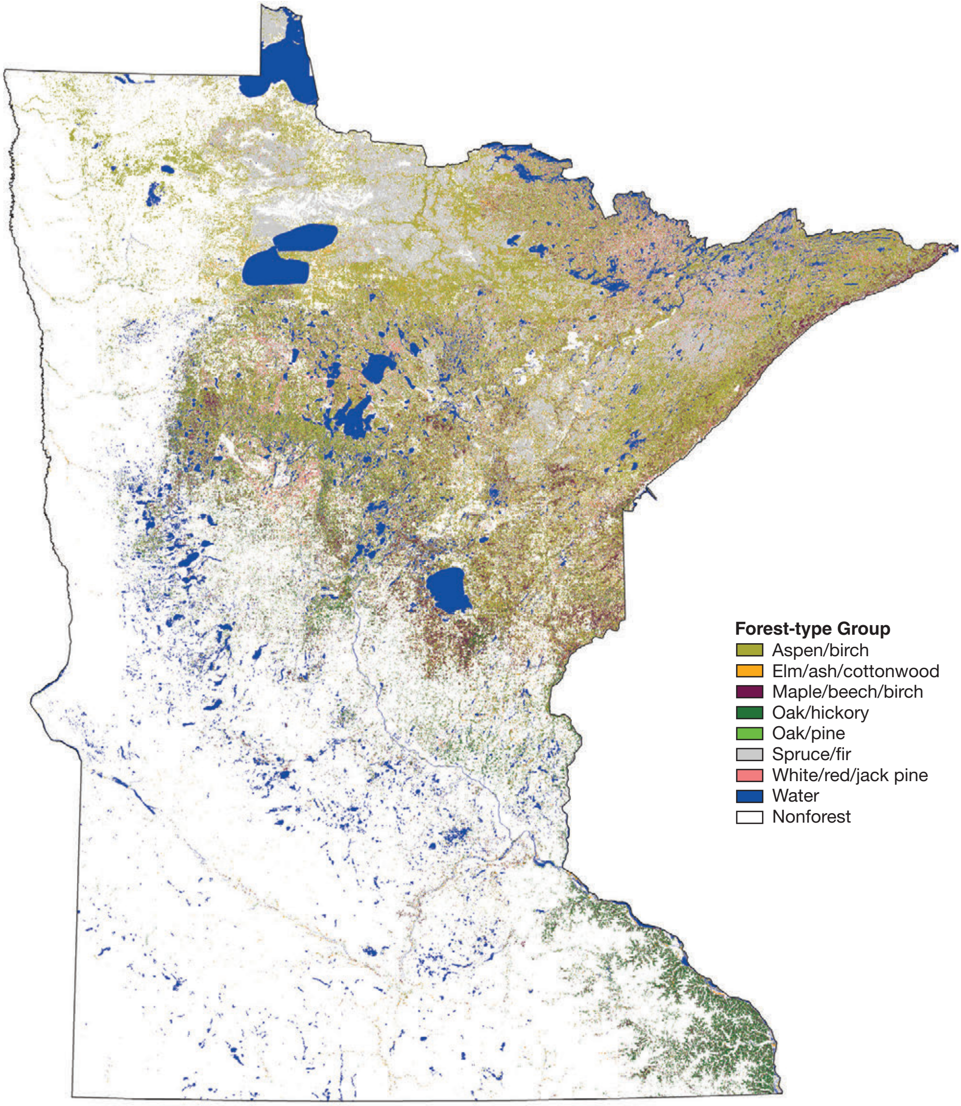


Figure 5.—FIA forest-type groups of Minnesota (Wilson et al. 2012).

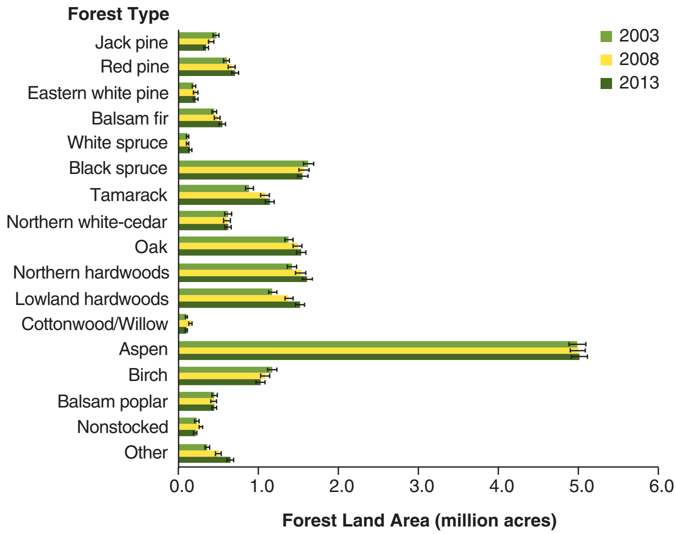


Figure 6.—Forest land area by Minnesota Department of Natural Resources (MN-DNR) cover type and inventory year, Minnesota. Error bars represent a 68 percent confidence interval around the estimated mean.

What this means

Softwood forest types are concentrated in the Laurentian Mixed Forest Province which lies in the transition zone between the Canadian boreal forests to the north and the broadleaf deciduous forests to the south and west. Aspen/birch is the predominant hardwood forest type in the Laurentian Mixed Forest Province. The northern reaches of the Eastern Broadleaf Forest Province are dominated by aspen and maple forest types giving way to drought-resistant oak/hickory in the south. The Prairie Parkland Province is characterized by intermingled prairie, groves, and strips of deciduous trees. Trees are commonly found near streams and on north-facing slopes. The upland forest in this province is dominated by oak/hickory while floodplains and moist hillsides are dominated by the elm/ash/cottonwood forest-type group.

Over the past decade increases in wetland forest types such as tamarack and lowland hardwoods have occurred at the expense of nonforested areas. A net gain of approximately 96 thousand acres of tamarack forest land and 133 thousand acres of lowland hardwoods from nonforest land occurred from 2003 to 2013. Further study is needed to determine reasons for these gains in forest land.

Stocking and Stand-size Class

Background

Stocking provides information on the degree of land occupancy by trees compared with a desired level for balanced health and growth. Stocking levels are calculated using a combination of number of trees, species, sizes, and spacing. A fully stocked stand indicates full utilization of the site. In stands of trees more than 5 inches in diameter a fully stocked stand would typically have a basal area of more than 80 square feet per acre. In a seedling-sapling stand, a fully stocked stand would indicate that the present number of trees is sufficient to attain a basal area of 80 square feet per acre when the trees are more than 5 inches in diameter.

What we found

Over half (56 percent) of the forest land in Minnesota is fully stocked or overstocked, 32 percent is medium stocked, and 12 percent is poorly stocked or nonstocked. Stocking levels are fairly consistent across the State. The proportion of seedling-sapling stands that are overstocked or fully stocked is 73 percent, followed by large diameter stands (54 percent) and medium diameter stands (42 percent).

Stocking levels vary by cover type (Fig. 7). Aspen forest land is over 68 percent fully or overstocked, while tamarack is only 36 percent fully or overstocked. In Minnesota, stocking is generally lower on low-lying cover types.

The forests of Minnesota are fairly evenly split between three stand-size classes. Large diameter stands, where a plurality of stocking is in hardwoods with a diameter at breast height (d.b.h.) of 11 inches and larger and softwoods with a d.b.h. of 9 inches and larger, are found on 28 percent of Minnesota forest land. Seedling-sapling stands, where a plurality of stocking is in trees less than 5 inches d.b.h., occupy 36 percent of the forest land. Medium diameter stands, where a plurality of stocking is in softwood trees with a d.b.h. from 5 to 9 inches and hardwood trees from 5 to 11 inches, occupy 35 percent of the forest land in Minnesota. The proportion of land area in each of the stand-size classes varies considerably by cover type (Fig. 8). Nearly 72 percent of the oak cover type is in the large diameter stand-size class. At the other end of the spectrum are tamarack and black spruce at less than 10 percent stocking in the large diameter size class.

Live basal area per acre of forest land for trees with a d.b.h. of 1 inch and larger was 78 square feet per acre in 2003 and 2008 but increased slightly to 81 square feet per acre in 2013.

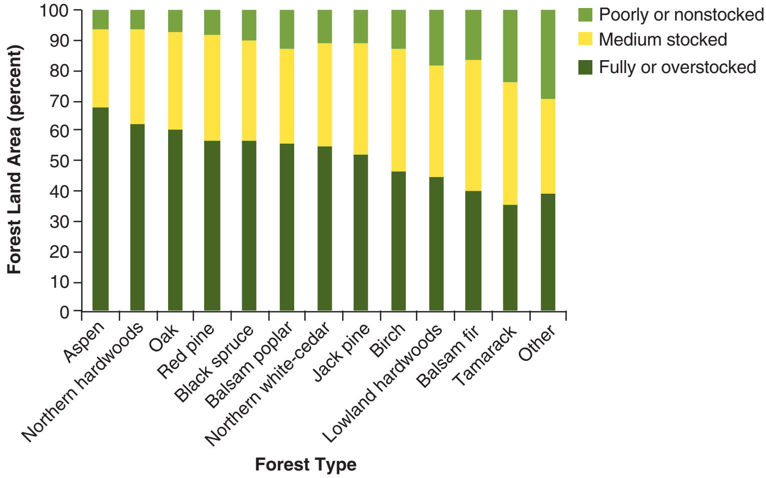


Figure 7.—Proportion of forest land area by stocking class for each MN-DNR cover type and stocking class, Minnesota, 2013.

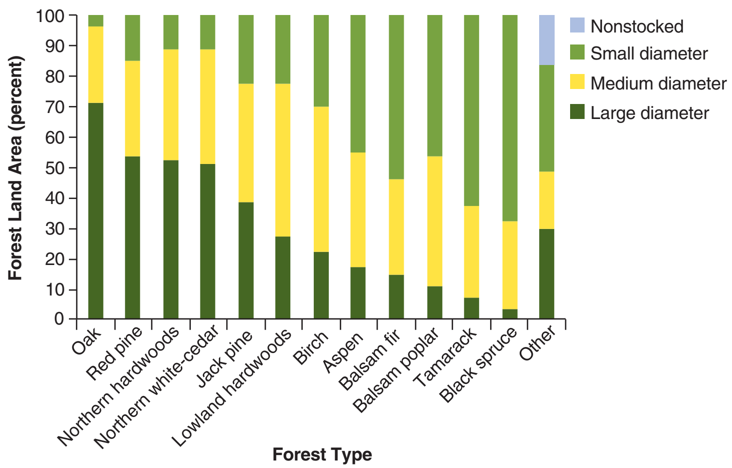


Figure 8.—Proportion of forest land area by MN-DNR cover type and stand-size class, Minnesota, 2013.

What this means

The density and size of stands across Minnesota provide information on the stages of stand development and forest stocking levels. Determining stages of stand development aids assessment of the future growth and mortality of forest resources. The high proportion of large diameter oak stands points to the difficulties in regenerating oak. Poor oak regeneration is generally tied to the cumulative impact of human actions and interventions. For instance, recurrent fire is important for oak regeneration because it eliminates many of oak's competitors. Fire suppression, therefore, may inadvertently lead to a decline in the oak resource. For oaks to remain a large component of Minnesota forests, promoting oak regeneration will be necessary.

Low stocking levels and a high proportion of small diameter stands for tamarack and black spruce are to be expected given the generally low site productivity of areas occupied by these lowland types. Of more concern is the small proportion of the northern white-cedar forest type in small diameter stands, as this also points to regeneration problems. Regeneration in northern white-cedar is often hindered by deer browsing.

Forest Ownership

Background

Land management objectives vary by owner (see section on Private Woodland Owner Survey). State and county lands are managed more intensively for timber production than are federal lands. Minnesota has the highest percentage of public ownership of any state in the eastern United States and the highest percentage of state and county ownership of any state in the Nation. Public ownership of forest land is concentrated in northern Minnesota.

What we found

Of 17.4 million acres of Minnesota forest land, 55 percent is in public ownership (Fig. 9), including 23 percent administered by the State of Minnesota; 15 percent administered by county and local governments; and 17 percent administered by the Federal government. Most of the Federal lands are concentrated in the northern part of the State on Voyageurs National Park, the Chippewa National Forest, the Superior National Forest, and the Superior National Forest's Boundary Water Canoe Area (BWCA) (Fig. 10).

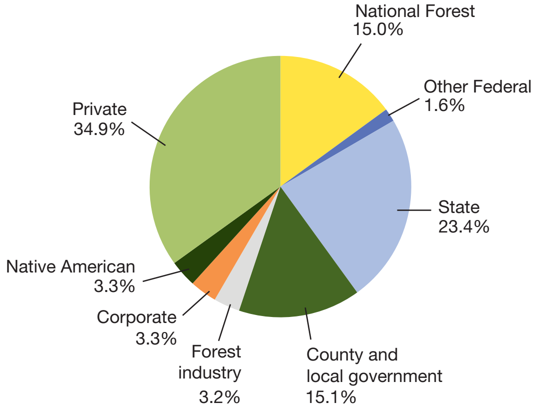


Figure 9.—Forest land by ownership or administering governmental unit, Minnesota, 2013.

The remaining 45 percent of Minnesota forest land is in private ownership and is divided between forest industry (3 percent), corporate (3 percent), Native American (3 percent), and private (35 percent). For simplicity, forest industry and corporate ownership will be lumped together and referred to as corporate throughout the rest of this report. The percentage of corporately owned forest land in Minnesota is less than that of Wisconsin (10 percent) and Michigan (14 percent). Nearly four-fifths of Minnesota corporate forest lands are located in just four counties (Itasca, Koochiching, Lake, and St. Louis). Even in these four counties, corporations own only 12 percent of the forest land. Additional information on other private forest lands is provided in the Private Woodland Owner Survey section.

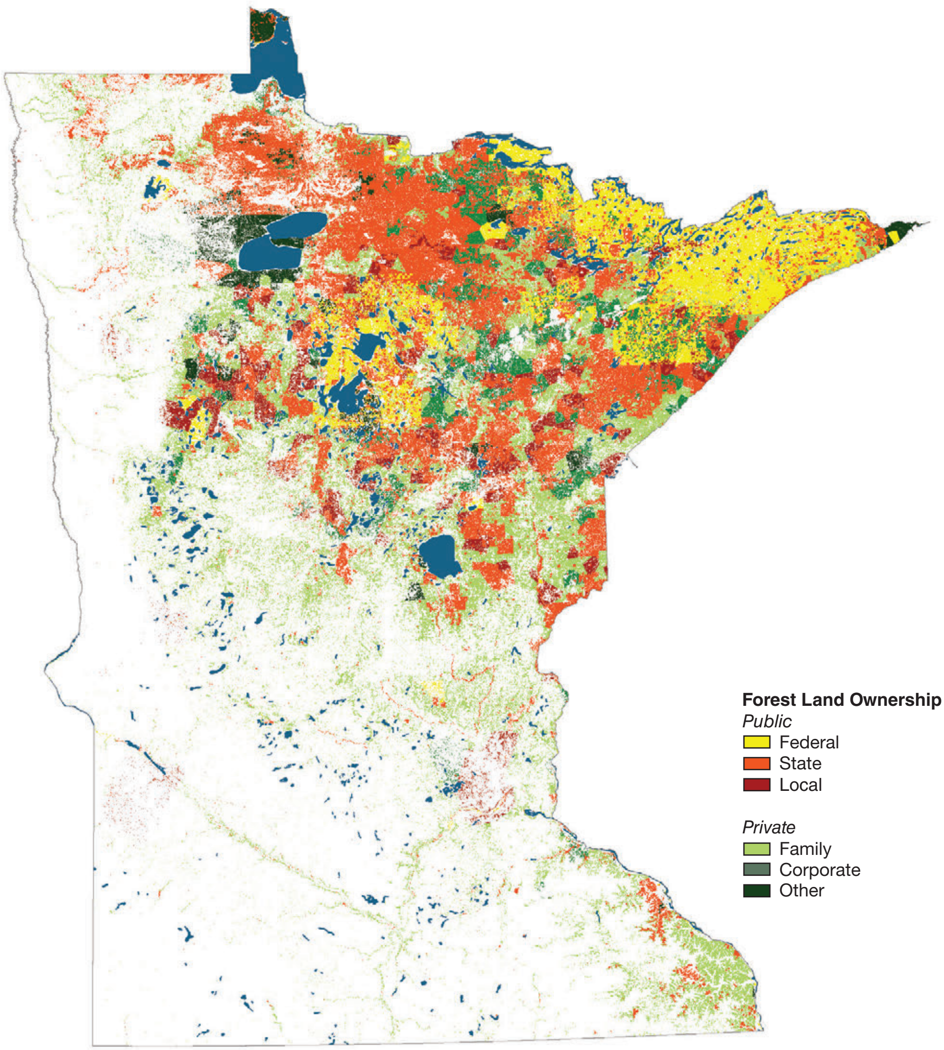


Figure 10.—Distribution of forest land by public and private ownership, Minnesota, 2013.

Figure 10 is a modeled representation of public and private forest land by ownership type developed by Hewes et al. (2014). Four types of public ownership are depicted: federal, state, county, and other public. Private ownerships consist of family (includes individuals and families), corporate, and other private (includes conservation and natural resource organizations, unincorporated partnerships and associations, and Native American tribal lands).

What this means

Management objectives often vary by owner (see Private Woodland Owner Survey section). Harvest rates of growing-stock volume on timberland expressed as a percentage of current timberland growing-stock volume are currently highest on county lands, followed by State, private, and finally Federal. In Figure 11, the estimates for each year are based on a rolling average of remeasured plots from the reporting year and the previous 4 years, so there is a lag in revealing ownership response to market conditions; however, there is evidence that some ownerships are more responsive to changes in stumpage prices than others. Average stumpage prices sold by public agencies in Minnesota peaked in 2005 (Deckard 2014), and while harvest rates for all ownerships declined, the decline was greatest on private ownerships.

The majority of public forest land ownership is concentrated in the northern part of the State while the population center is in the Twin Cities metro area. Urban and suburban forests are where the intense interaction of people and forests presents special management challenges that have high potential to affect the quality of life for millions of residents (Shifley et al. 2014). The high level of interaction between people and trees in and around urban areas makes these areas of particular significance to managers (Radeloff et al. 2005).

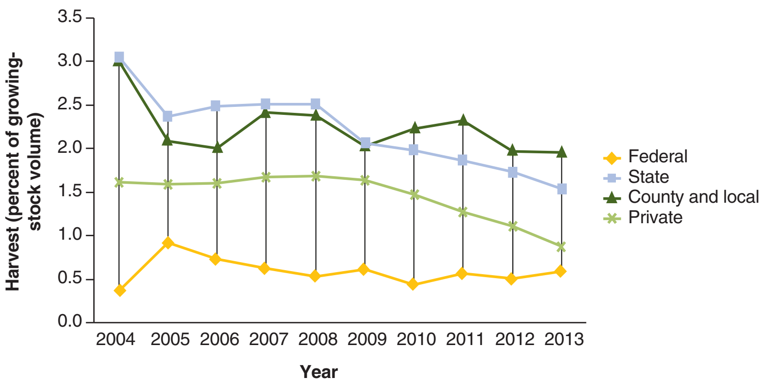


Figure 11.—Harvest of growing-stock volume on timberland by ownership group and year, Minnesota, 2004 through 2013.

Number of Trees and Size Distribution

Background

An estimate of the number of trees in a forest is useful when combined with information on the diameter class distribution. Young forests have many more trees per acre than older forests; older forests usually have fewer trees, but the trees are larger and have much more biomass than younger forests. It is the number of trees and their diameter distributions that are important.

What we found

In Minnesota there are currently an estimated 14.2 billion trees on forest land. Of these trees, 83 percent are saplings (trees from 1 to 4.9 inches at d.b.h), 14 percent are poletimber-size trees (5 to 9 inches d.b.h. for softwoods and 5 to 11 inches d.b.h. for hardwoods), and 3 percent are sawtimber-size trees. The high number of saplings is consistent with natural processes of regeneration and subsequent self-thinning. Nearly two-thirds (64 percent) of the trees in Minnesota are hardwoods, and the rest are softwoods. Quaking aspen alone accounts for nearly 25 percent of the total number of trees in Minnesota.

From 2003 to 2013, the total number of trees on forest land in Minnesota increased, with the number of saplings increasing by 20 percent, sawtimber trees increasing by 9 percent, and poletimber increasing by 8 percent (Fig. 12). Nearly all of the increase in the number of poletimber trees occurred between 2008 and 2013.

Figure 12.—Number of live trees on forest land by tree size class and inventory year, Minnesota.

Figure 13 provides a breakdown of the number of trees in Minnesota in each tree-size class by species. There have been large increases in the number of white spruce and

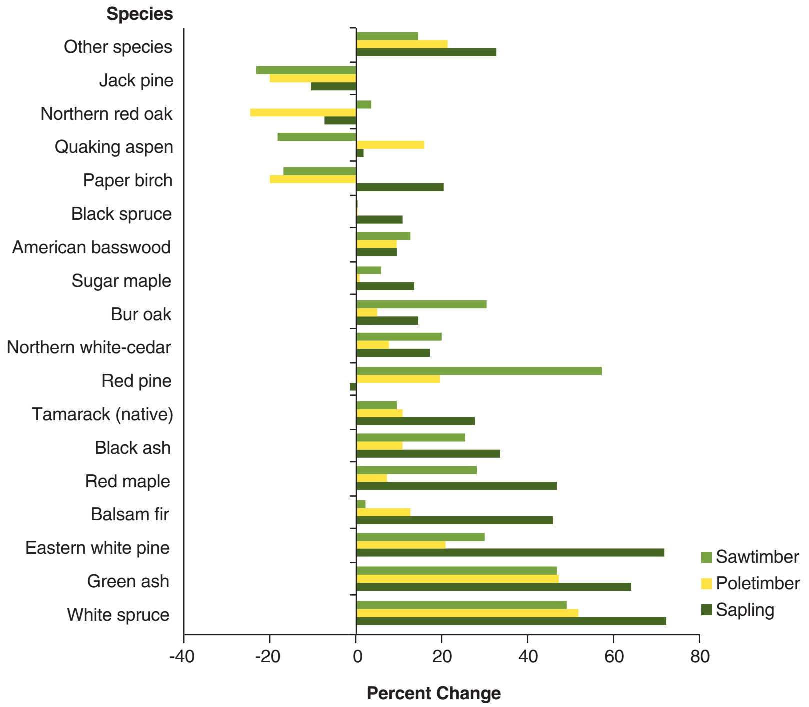


Figure 13.—Percent change in the number of live trees on forest land by species and size class, Minnesota, 2003 to 2013.

green ash trees in all size classes. Conversely, the number of jack pine trees in each size class has decreased. For quaking aspen, there has been a decrease in the number of sawtimber-size trees but increases in the number of poletimber and sapling-size trees.

Basal area is the cross-sectional area of a tree 4.5 feet above the ground. The mean basal area per tree for the stand is calculated by measuring the cross-sectional area of all the trees in a stand and taking the average. Because it is easier to visualize tree diameter than mean basal area, the concept of quadratic mean diameter (QMD) was introduced. The QMD of a stand is the diameter of a tree with basal area equal to the mean basal area per tree of the stand. QMD is usually calculated for trees over a certain minimum diameter, in this case 5 inches d.b.h.

Trees in Minnesota are generally smaller than the average for the conterminous United States (Table 3), partly because much of Minnesota lies in the transition zone between forest and prairie. Smaller diameters are also due in part to management favoring pioneer species, such as aspen and jack pine, that tend to mature quickly but rarely attain the size of late successional species like sugar maple and white pine. Figure 14 displays the QMD by county for trees over 5 inches d.b.h. A nonforest mask, derived from the National Land Cover Dataset (NLCD), was placed over the counties so that colored shading would only appear on forested areas.

Table 3.—Minnesota in context: Quadratic mean diameter (QMD) and average number of trees (5 inches d.b.h. or larger) per acre, 2013

Geographic area	QMD	Number of trees per acre of forest land	Number of trees per acre of land
Coterminous United States	10.4	135.9	49.4
Lake States (MN, MI, WI)	9.3	154.5	69.4
Minnesota	8.8	139.1	47.5

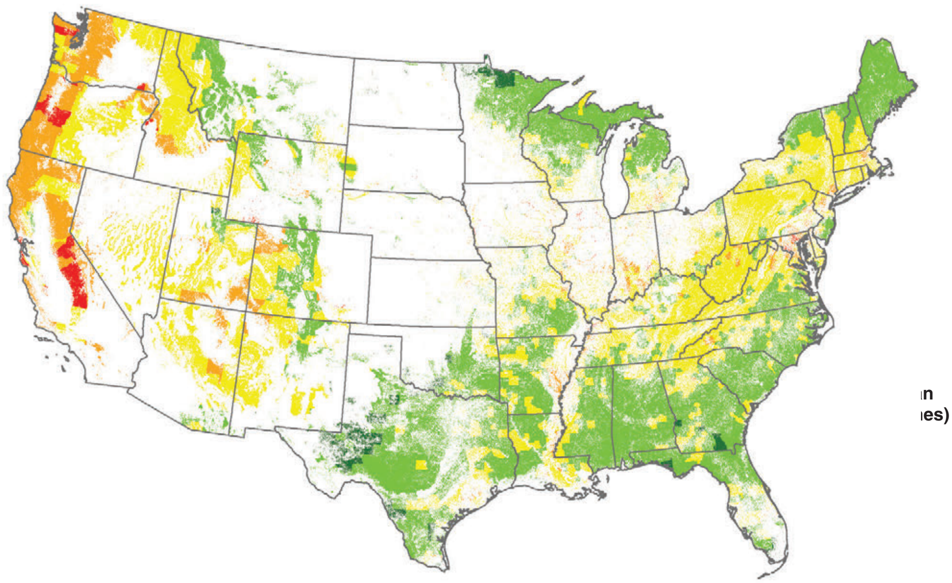


Figure 14.—Quadratic mean diameter by county for all trees 5 inches d.b.h. and larger on forest land, United States, 2013.

What this means

Increases in the number of poletimber-size white spruce and red pine trees are the result of artificial regeneration efforts (planting and seeding) conducted years ago. Nearly 80 percent of artificially regenerated timberland in Minnesota is in these two species. Jack pine regeneration is facilitated by fire. Fire suppression and the jack pine budworm have been significant factors in the decline in the number of jack pine trees. Paper birch is susceptible to the bronze birch borer and Armillaria root disease. Recent droughts have also had an adverse impact on paper birch. The increase in the number of quaking aspen poletimber trees is good news for the timber industry as this is the preferred size class for the wood pulp industry.

Tree Biomass

Background

Biomass estimates are increasing in importance for analyses of carbon sequestration, wood fiber availability for fuel, and other issues. Traditionally, timber harvests have been measured in board feet or cubic feet. Increasingly they are measured in green tons or dry tons. In Minnesota the ratio of green tons to dry tons is approximately 1.9 to 1.0.

The average aboveground dry weight of a tree (including stump, bole, and limbs but excluding foliage and roots) increases dramatically with increasing tree diameter (Table 4). Trees in the 7.0- to 8.9-inch diameter size class, for example, weigh slightly more than twice the weight of trees in the 5.0- to 6.9-inch class.

Table 4.—Average aboveground tree biomass by diameter class and major species group, Minnesota, 2013

Diameter class	Softwoods	Hardwoods
--- Inches ---	*------------------------------------ Dry pounds*	*---------------------------------*
1.0-2.9	5	7
3.0-4.9	30	44
5.0-6.9	90	126
7.0-8.9	192	269
9.0-10.9	329	459
11.0-12.9	507	698
13.0-14.9	728	993
15.0-16.9	1,014	1,349
17.0-18.9	1,408	1,788
19.0-20.9	1,816	2,255
21.0-28.9	2,861	3,451
29.0+	6,350	7,001

What we found

Biomass, measured as all live aboveground tree biomass on forest land, was estimated at 438 million dry tons in 2003 and had increased to 458 million dry tons by 2008 and to 484 million dry tons in 2013. In both 2003 and 2008 there was an average of 27 dry tons of live aboveground tree biomass per acre of forest land. By 2013 this had increased to 28 tons per acre. The distribution of forest biomass per acre of land is presented in Figure 15 and Table 5.

In 2013, 16 percent of the live tree aboveground biomass on timberland was in saplings (trees less than 5 inches d.b.h.) while 84 percent was in trees 5 inches in d.b.h. and larger. The boles of trees 5 inches d.b.h. and larger accounted for 64 percent of live tree aboveground biomass, while their top and limbs accounted for 16 percent, and their stumps accounted for 4 percent (Fig. 16). Nearly three-quarters of the total biomass was composed of hardwood species.

The total live tree aboveground dry biomass on timberland in 2013 was 443 million tons, a 6 percent increase from the 418 million tons reported in 2008 and a 24 percent increase from the 398 million tons reported in 2003.

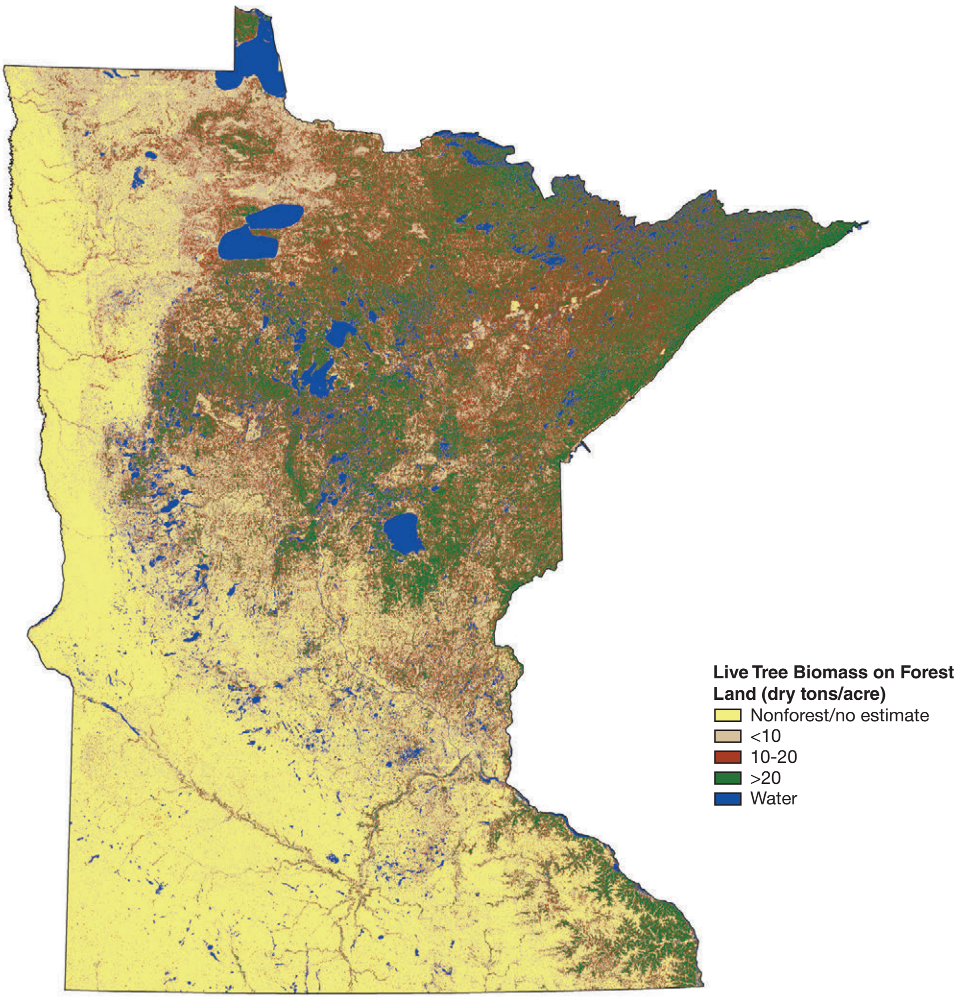


Figure 15.—Average live tree biomass for all trees on forest land, Minnesota, 2013.

Table 5.—Minnesota in context: Aboveground live tree biomass per acre of forest land

Geographic area	Dry tons per acre
Coterminous United States	41
Lake States (MN, MI, WI)	36
Minnesota	28

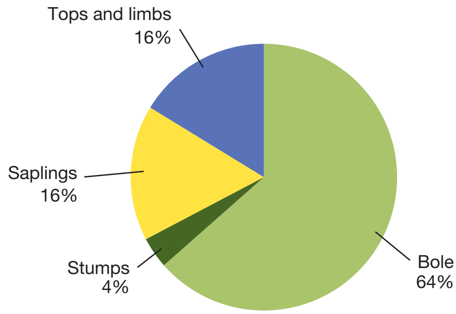


Figure 16.—Live tree biomass on timberland by component, Minnesota, 2013.

What this means

Minnesota is continuing to gain aboveground live tree biomass due primarily to increases in forest land area. However, increasing demand for woody biomass for the production of energy will place additional demands on forest planning and management to ensure that the resource is managed sustainably.

Volume and Species Composition

Background

Current volumes can be compared to rates of harvest to help determine the sustainability of current and projected future harvest levels. Because certain species are more economically desirable than other species, it is important to view volume information on a species-by-species basis.

What we found

Volume on timberland

The volume of all live trees on timberland increased from 14.3 billion cubic feet in 1977, to 16.0 billion in 2003, to 16.4 billion in 2008, and 17.3 billion in 2013 (Table 6). Historically, over 13 percent of live tree volume falls in the rough and rotten cull category, and this trend held true in the 1977, 2008, and 2013 inventories. The cull proportion reported in 2003, however, was only half this rate. Rough and rotten cull volume went from 14 percent of live volume in 1977 to 6 percent in 2003 and back to 14 percent in 2008 and 2013. If the 2003 cull proportion is adjusted to reflect historic levels, growing-stock volume would have increased from 12.3 billion cubic feet in 1977 to 14.1 billion in 2003, 14.2 billion in 2008, and 15.0 billion in 2013 while rough and rotten cull would have increased from 1.9 billion in 1977 to 2.2 billion in 2003, 2.3 billion in 2008, and 2.4 billion in 2013.

Table 6.—Live tree volume on timberland by tree class and inventory year, Minnesota

Tree class	1977	2003	2003 adjusted	2008	2013
	Million ft³				
Growing stock	12,350	14,937	14,100	14,155	14,990
Cull	1,949	1,030	2,200	2,271	2,357
Total	14,299	15,968	16,300	16,425	17,347

Figure 17 shows the change in all live volume on timberland by species for the 12 species having the largest volume in 2013 (75 percent of the total). Between 2003 and 2013, there were winners and losers. The big winners included red pine, which increased in volume by 48 percent, bur oak (27 percent), northern white-cedar (19 percent), black ash (16 percent), and American basswood (11 percent). The losers included paper birch with a 19 percent decline and quaking aspen with a 5 percent decline.

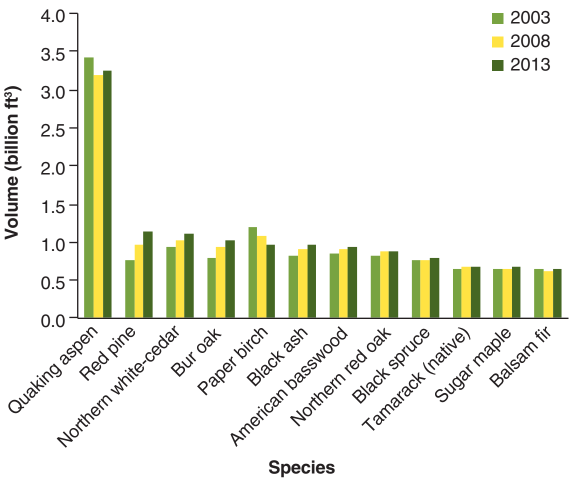


Figure 17.—Live tree volume on timberland by species and inventory year, Minnesota.

Aspen is concentrated in northeastern Minnesota. The decrease in growing-stock volume of aspen from 2003 to 2008 followed by a smaller increase from 2008 to 2013 is reflective of the economic recession of 2008 and the resulting decline in the demand for paper and boards. Harvest removals of live aspen declined by 29 percent from the 2008 inventory to the 2013 inventory. As a result, all live aspen volume on timberland increased from 3.2 billion cubic feet in 2008 to 3.3 billion cubic feet in 2013.

The area of timberland increased by 5 percent from 2003 to 2008. This new timberland was relatively sparsely treed, resulting in a decline in the overall volume per acre on timberland from 1,101 cubic feet in 2003 to 1,075 cubic feet in 2008. The area of timberland increased by 3 percent from 2008 to 2013. Volume per acre on timberland also increased over this period, from 1,075 in 2008 to 1,108 in 2013. The average volume per acre on lands that reverted from nontimberland to timberland over the last 5 years was only 406 cubic feet.

Volume on forest land

Ninety-eight percent of all live tree volume on forest land comes from just 27 of the 66 species measured during the 2013 inventory (see Appendix 1 for list of species measured). Leading the list is quaking aspen at 18 percent, followed by red pine at 6 percent, northern white-cedar at 6 percent, and paper birch at 6 percent. Maps of species volume per acre of forest land by county are presented in Figures 18 and 19.

What this means

Aspen volume on timberland increased slightly from 2008 to 2013 due to a 29 percent decline in aspen harvest removals and a 23 percent increase in volume in the 5- to 7-inch diameter class. In the short term, aspen volumes are expected to increase as large areas of regenerated aspen continue to grow into poletimber. Demand for aspen and other species may increase as demand for new wood-based products and possibly for bioenergy increases in future years

All of the top 30 species by volume on forest land have had increasing or steady volumes except for paper birch, jack pine, and balsam poplar, which had high rates of mortality (3.2, 2.1, and 5.1 percent, respectively), and northern red oak and eastern cottonwood where regeneration may be a problem.

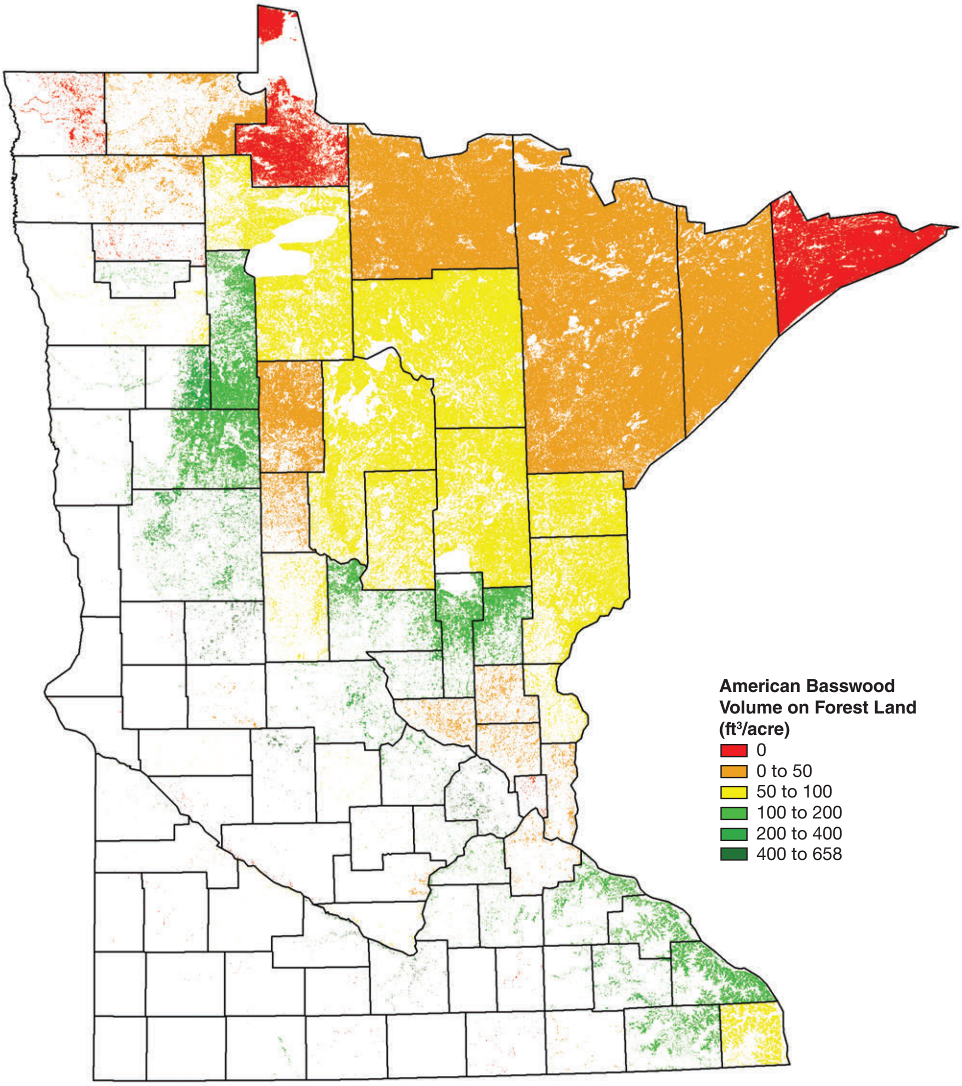


Figure 18.—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013. (Continued on next page)

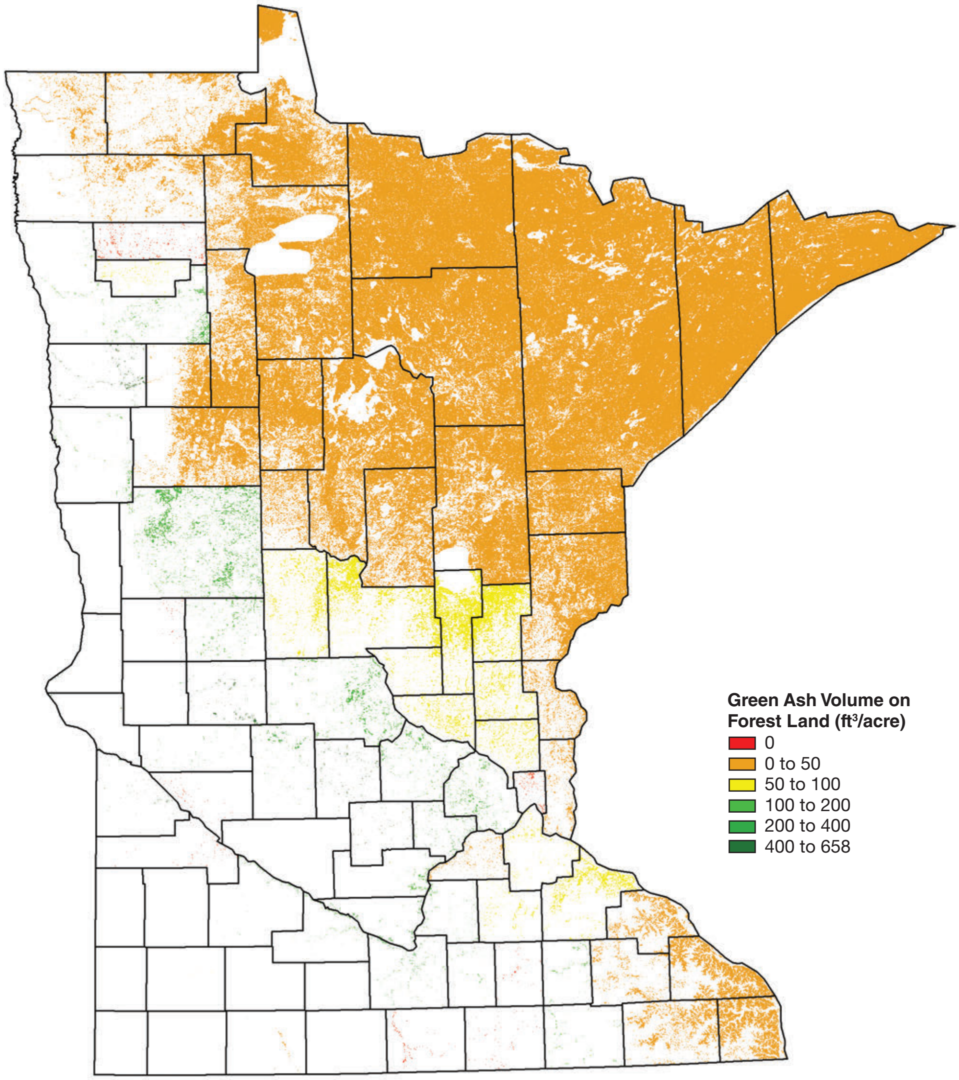


Figure 18. (Continued)—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013. (Continued on next page)

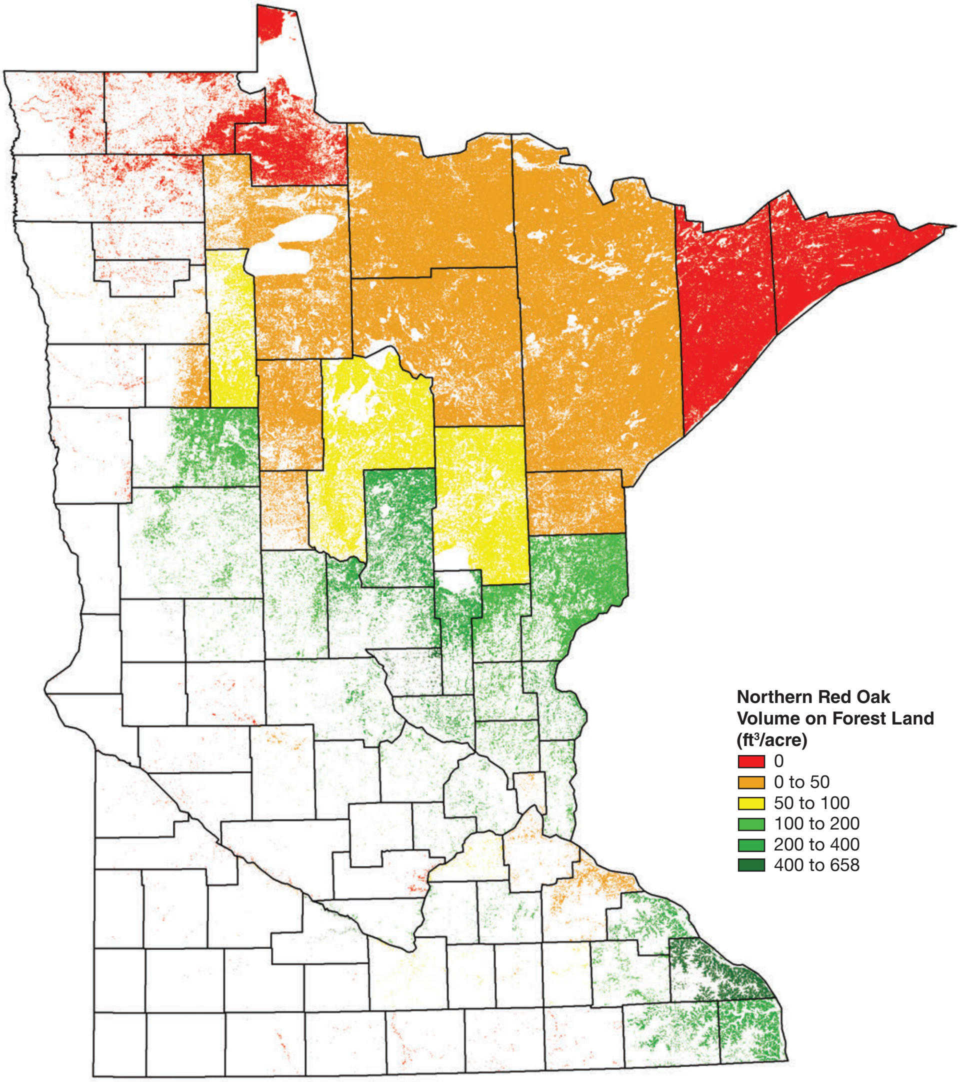


Figure 18. (Continued)—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013.
(Continued on next page)

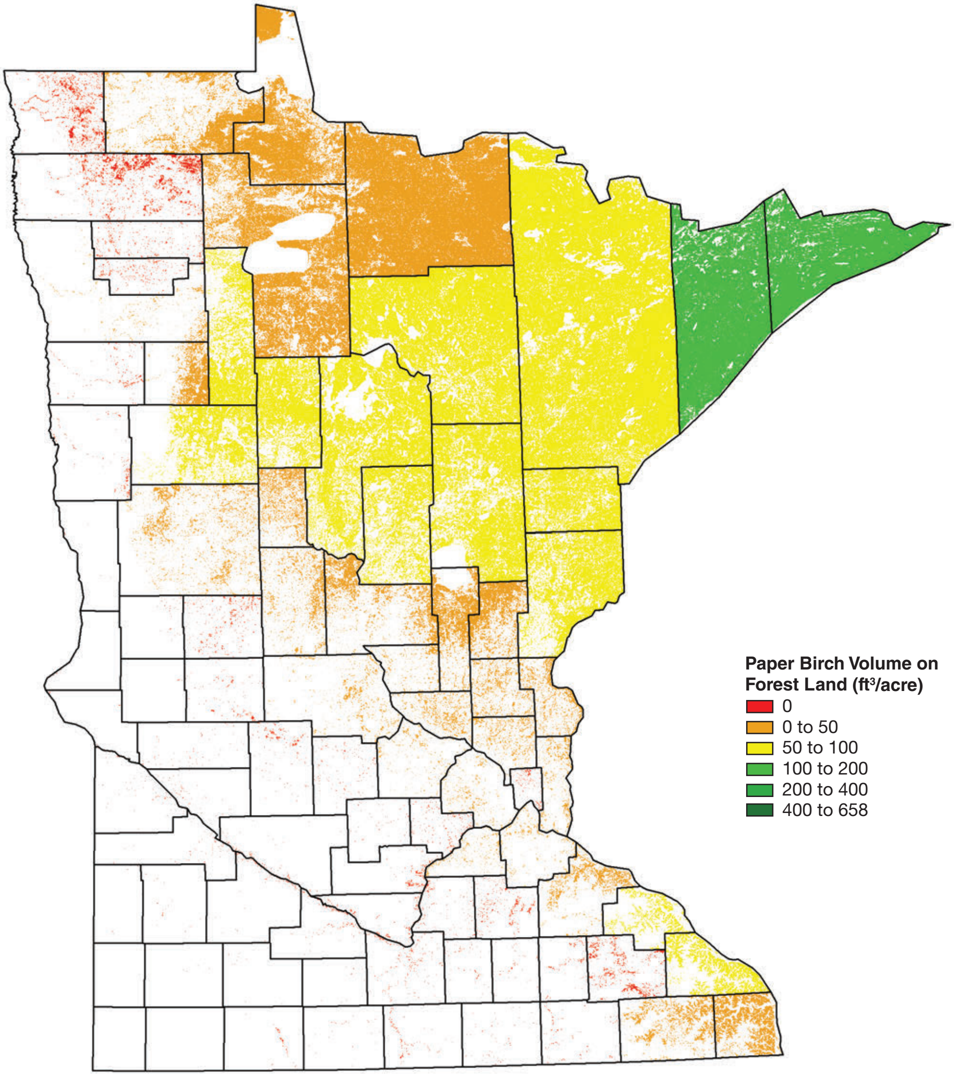


Figure 18. (Continued)—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013. (Continued on next page)

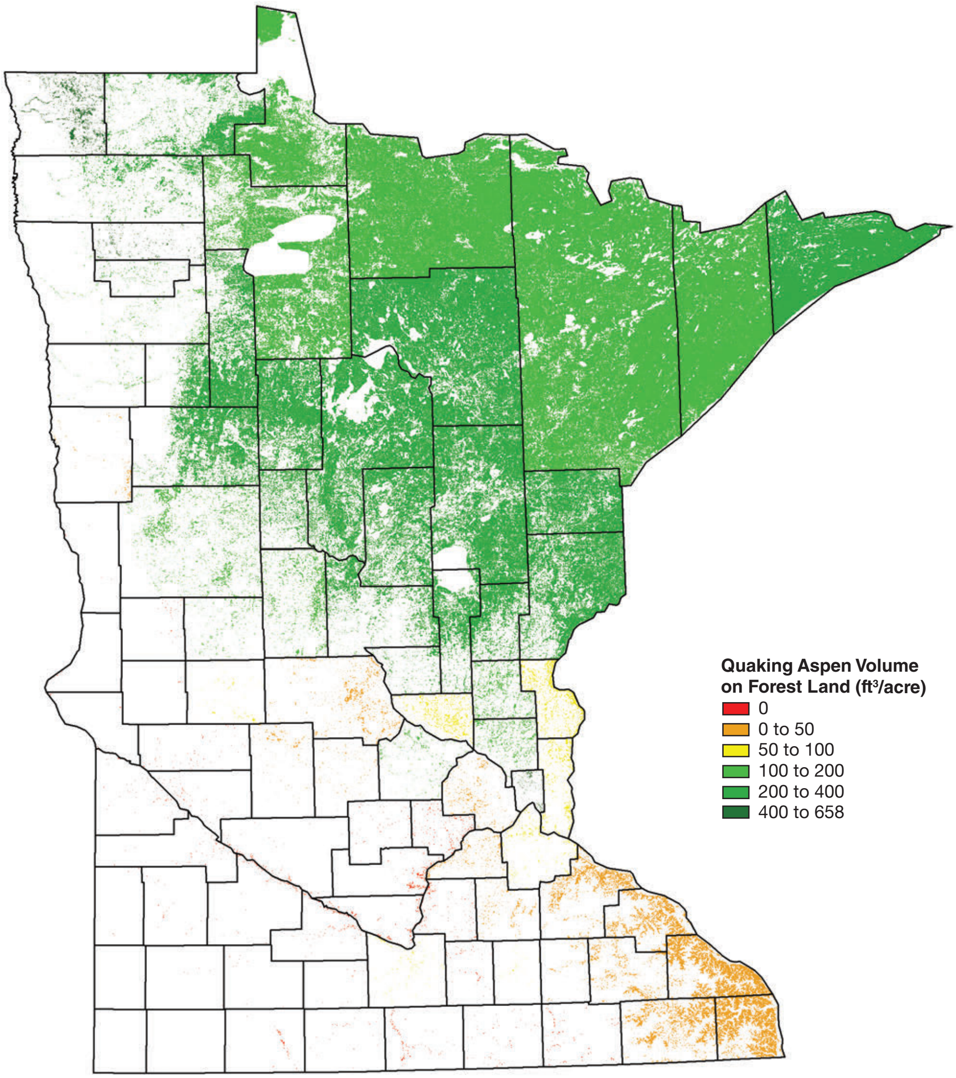


Figure 18. (Continued)—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013.
(Continued on next page)

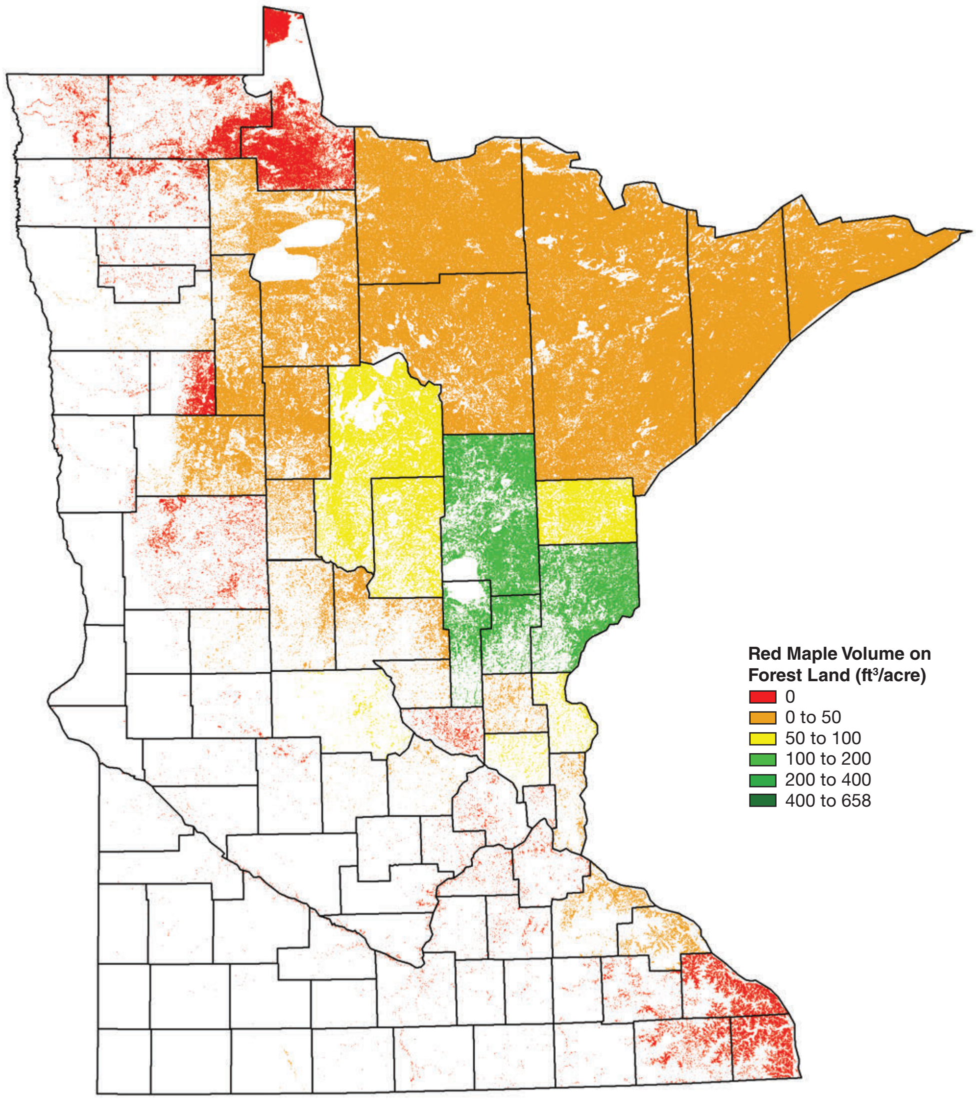


Figure 18. (Continued)—Live tree volume per acre on forest land for selected hardwood species, Minnesota, 2013.

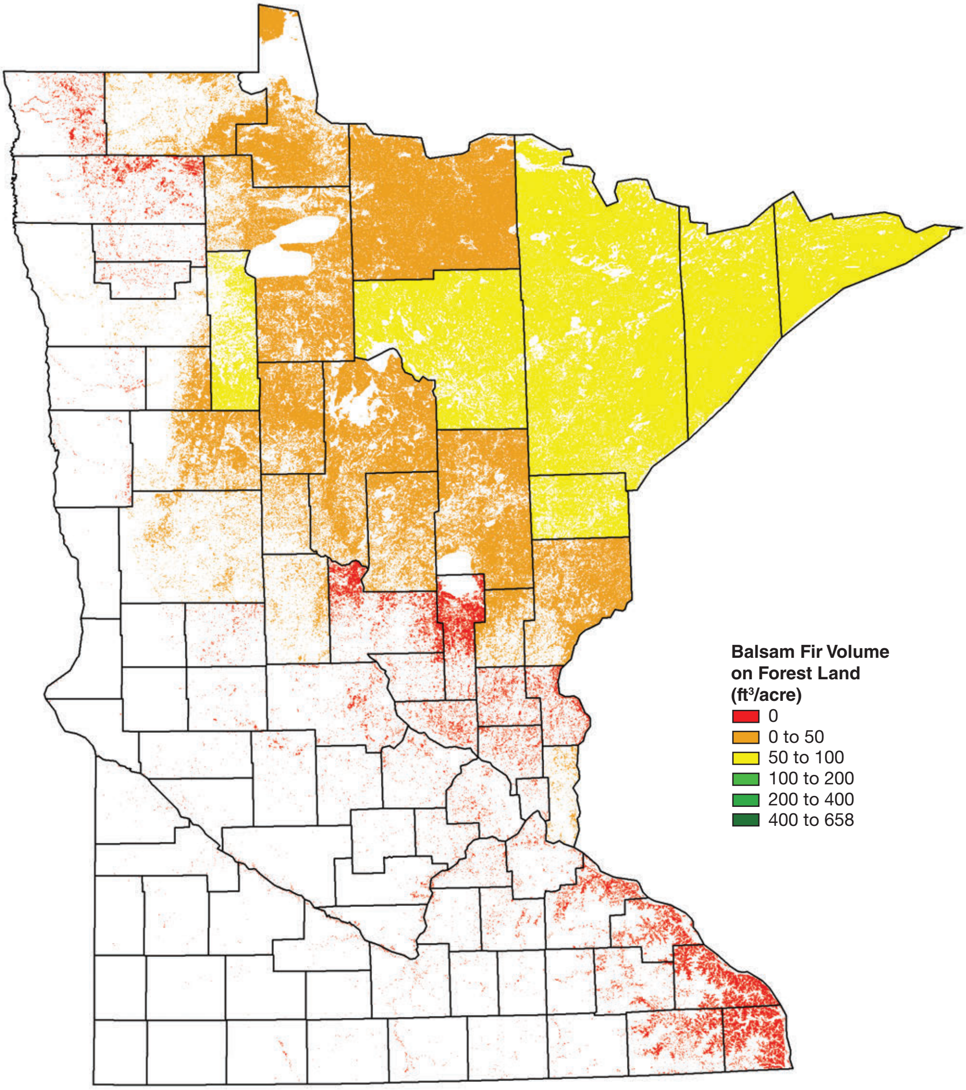


Figure 19.—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013. (Continued on next page)

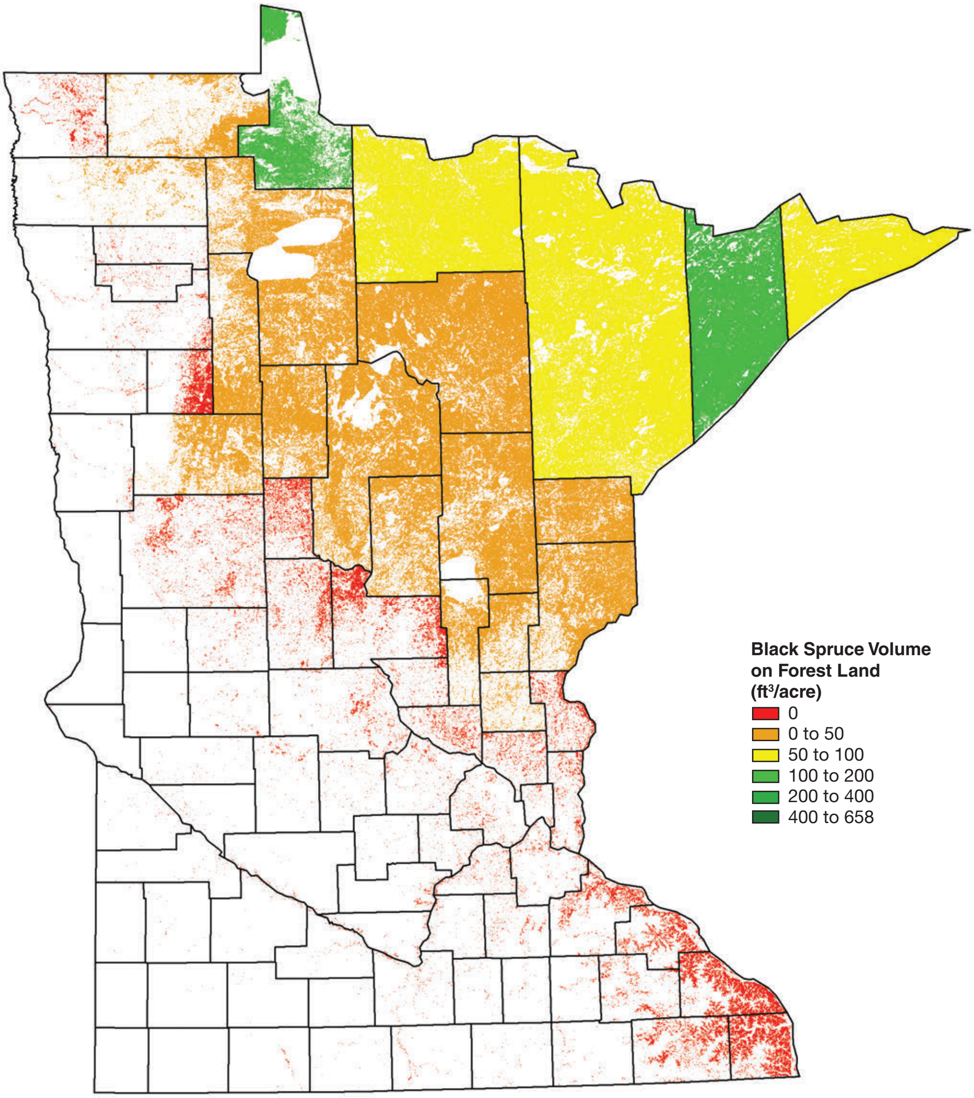


Figure 19. (Continued)—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013. (Continued on next page)

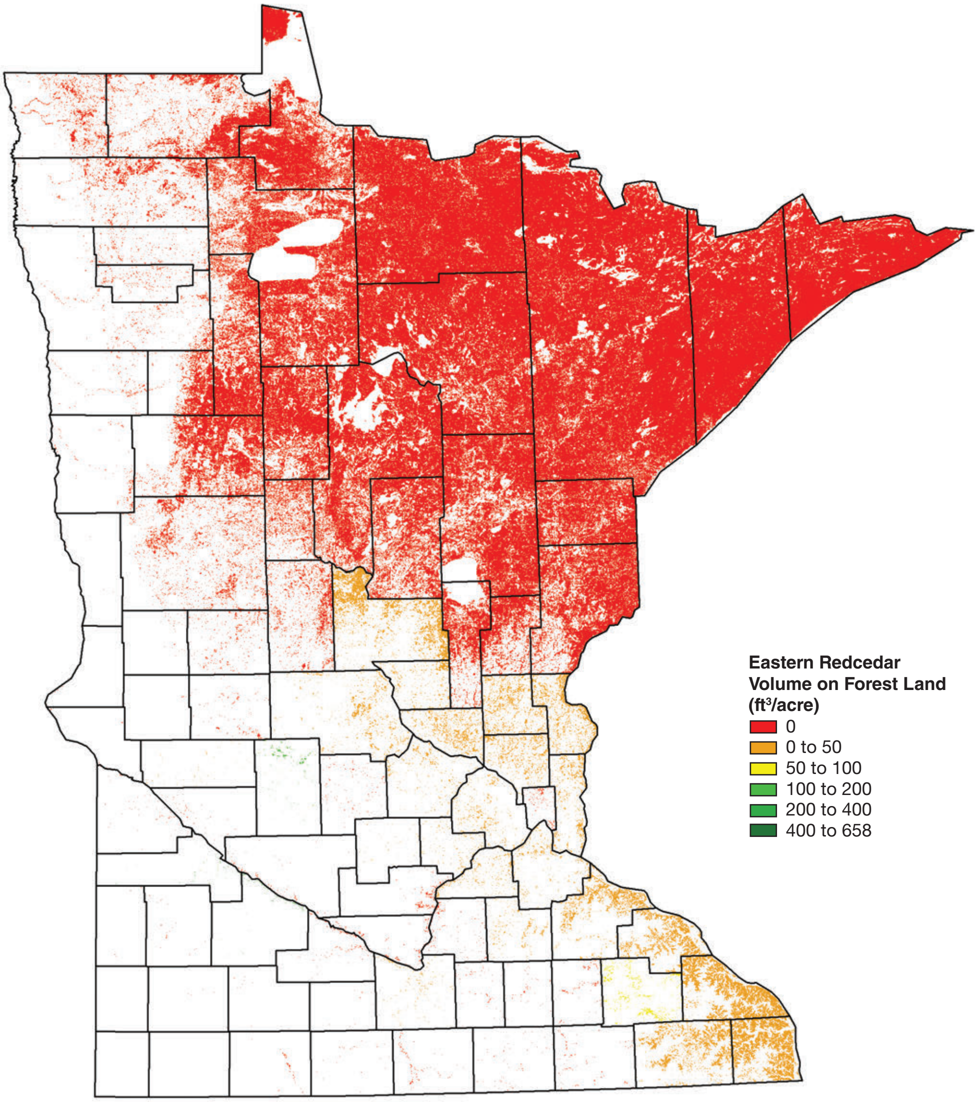


Figure 19. (Continued)—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013.
(Continued on next page)

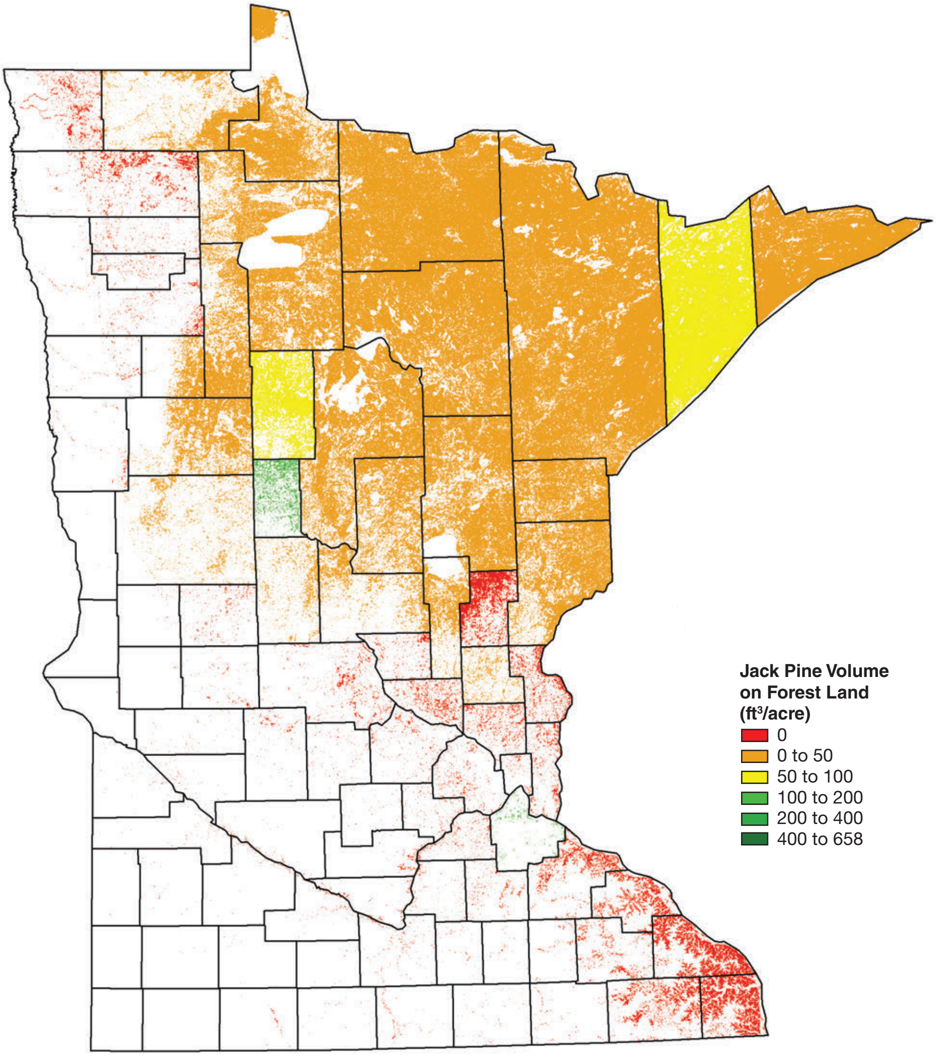


Figure 19. (Continued)—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013. (Continued on next page)

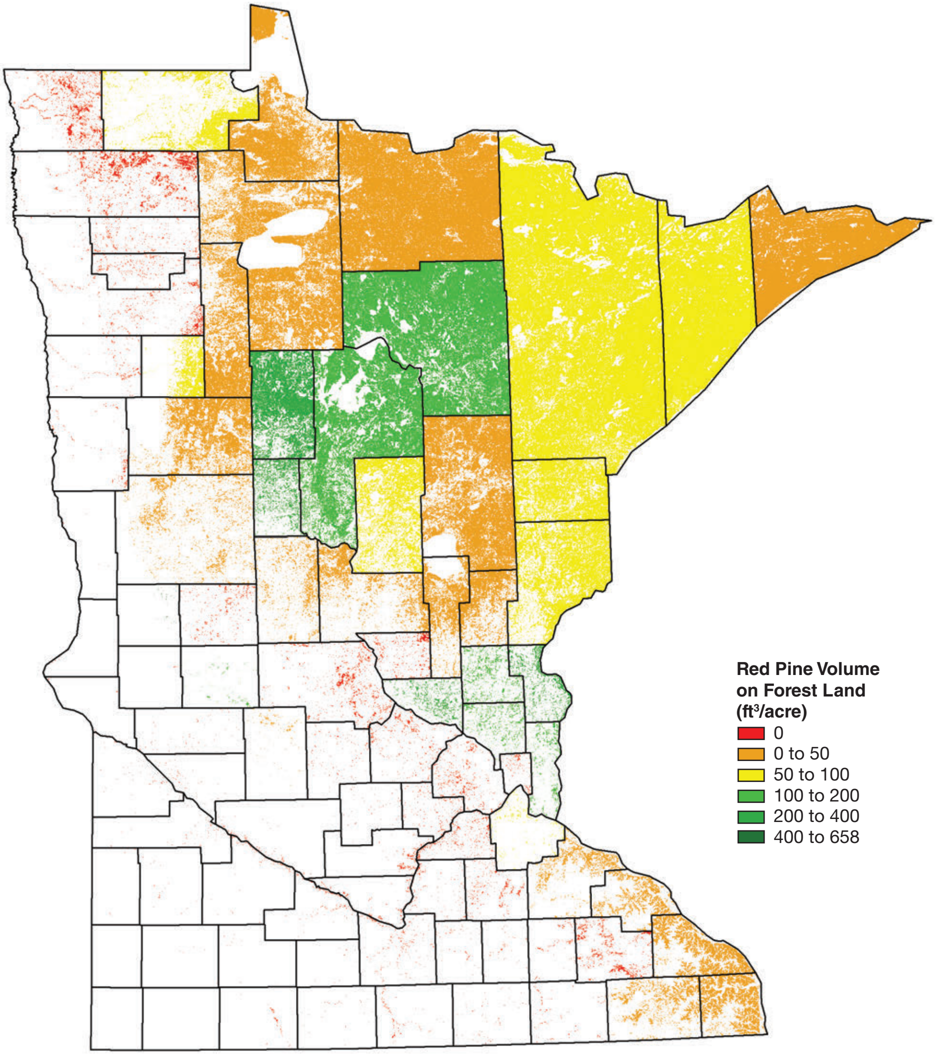


Figure 19. (Continued)—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013. (Continued on next page)

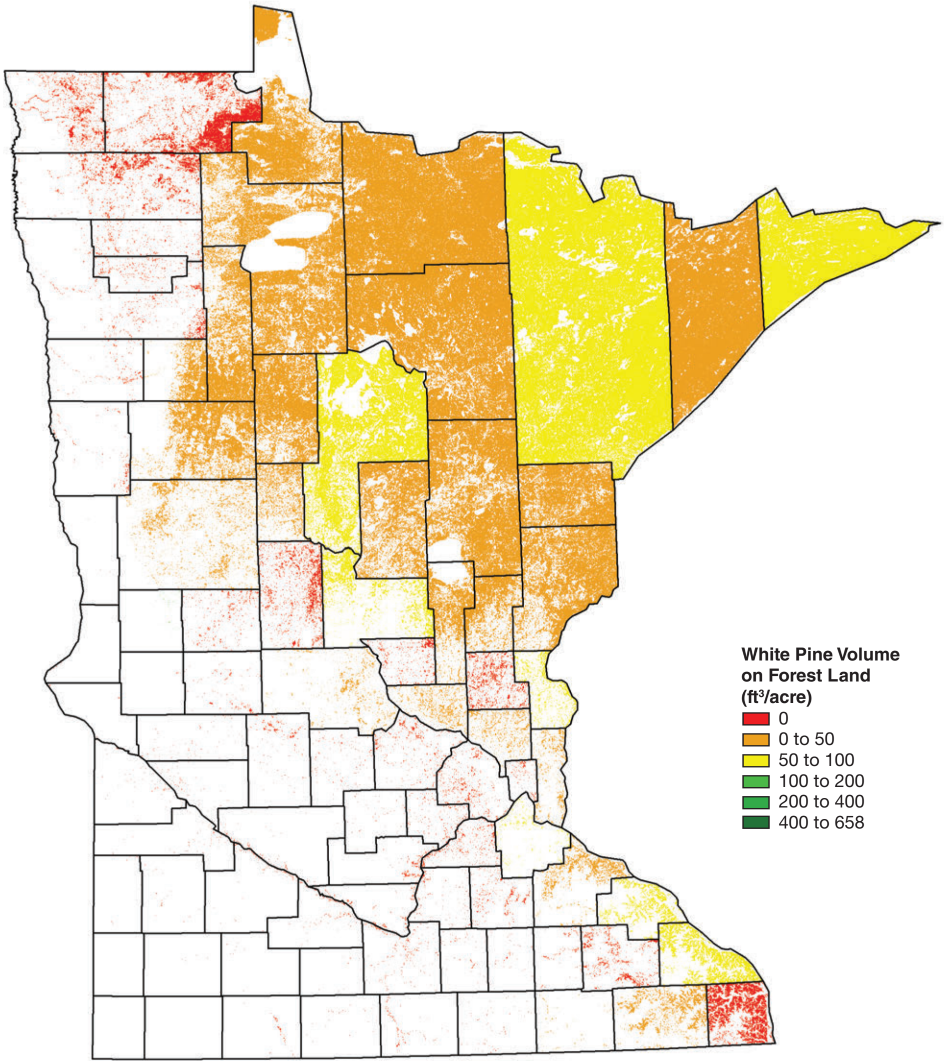


Figure 19. (Continued)—Live tree volume per acre on forest land for selected softwood species, Minnesota, 2013.

Sawtimber Volume and Quality

Background

A board foot is a unit of measure 1 inch by 12 inches by 12 inches. Softwood sawtimber is primarily valued for dimensional lumber, while hardwood sawtimber is valued for use in flooring and furniture. To qualify as sawtimber-size trees under the FIA definition, softwood trees must have a d.b.h. of at least 9 inches and hardwoods must have a d.b.h. of at least 11 inches.

Tree grade, as determined in the field, is based on tree diameter and the presence or absence of knots, decay, or curvature of the bole. The value of sawtimber varies greatly by species and tree grade. The highest quality trees are graded 1, while the lowest quality trees receive a tree grade of 5. Trees not meeting grade 5 standards are classified as cull. The grading system has changed a number of times including between the 1990 and 2003 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 (Pugh et al. 2012).

What we found

Sawtimber volume on timberland totaled 38.6 billion board feet in 2013. This is up from the 35.4 billion board feet reported in 2008. This increase was evenly split between softwoods and hardwoods (Fig. 20).

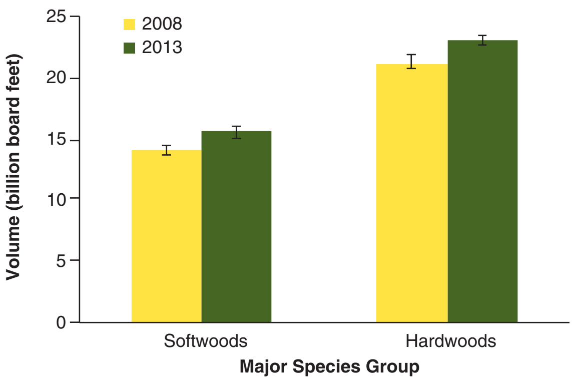


Figure 20.—Sawtimber volume on timberland by major species group and inventory year, Minnesota. Error bars represent a 68 percent confidence interval around the estimated mean.

Of the 66 tree species measured on FIA plots during the 2013 inventory, 44 contributed to sawtimber volume on timberland. Ninety-one percent of the sawtimber volume on timberland was found in just 17 species (Fig. 21). The volume in five species (quaking aspen, tamarack, paper birch, bigtooth aspen, and jack pine) decreased from 2008 to 2013.

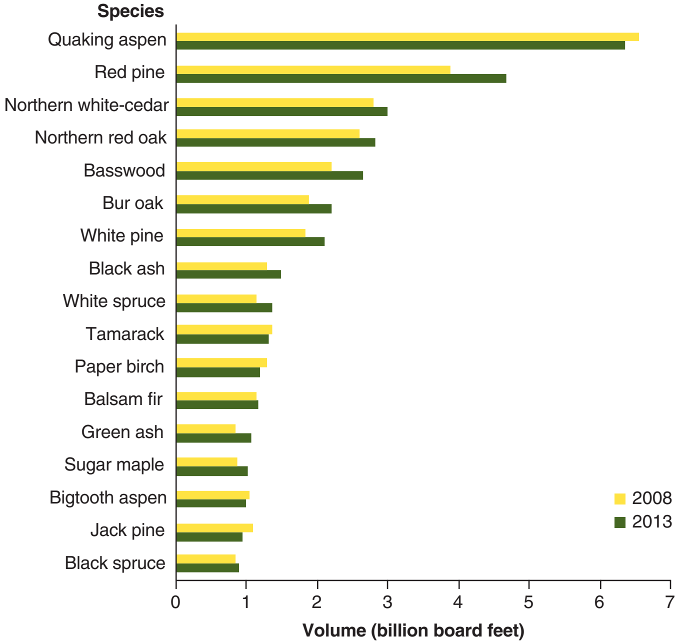


Figure 21.—Sawtimber volume on timberland by selected species and inventory year, Minnesota.

While 49 percent of softwood sawtimber is tree grade 1, only 6 percent of hardwood sawtimber volume is in tree grade 1 (Fig. 22). This is the lowest percentage of any eastern state with the exception of Oklahoma (Fig. 23). The high concentration of short-lived hardwood species (primarily aspen and birch) in the northern part of the State combined with the more arid conditions in the prairie west are largely responsible for the low percentage of grade 1 hardwood trees.

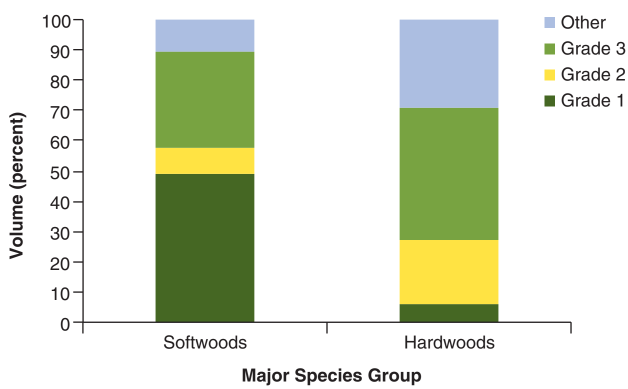


Figure 22.—Sawtimber volume on timberland by major species group and tree grade, Minnesota, 2013.

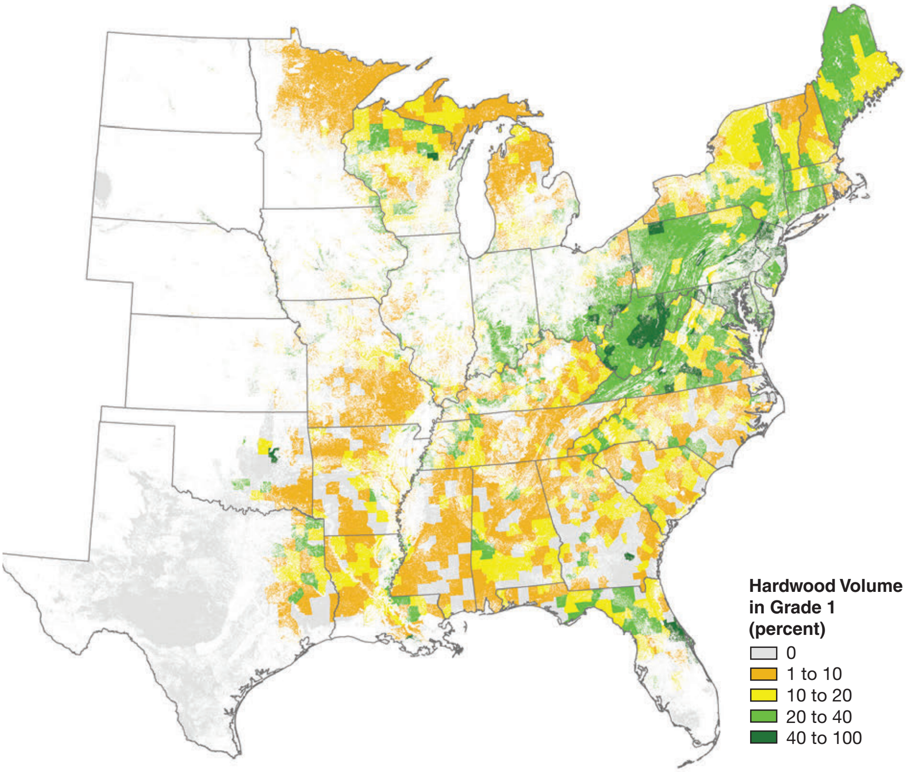


Figure 23.—Percentage of timberland hardwood growing-stock volume in grade 1, eastern United States, 2013.

What this means

The volume of sawtimber is decreasing for pioneer species like quaking aspen, paper birch, and jack pine. A decrease in the volume of aspen sawtimber is partly due to natural succession and partly due to forest management efforts to harvest senescent trees to make way for younger more vigorous forests.

Sawtimber per acre volumes are highest on federally administered timberland (3,408 board feet), followed by privately owned land (2,711 board feet), and finally state and county land (1,884 board feet). This reflects the removals levels of sawtimber trees on timberland for each of the ownership groups. Sawtimber removals as a percentage of standing sawtimber volume on land that was timberland at both the beginning and end of the remeasurement period is lowest for Federal ownership (0.6 percent), followed by private ownership (0.9 percent), and finally state and local government ownership (2.0 percent).

Tree Volume Net Growth

Background

Net growth is computed by measuring a tree at two points in time and determining the average annual change in volume over the period. If the volume on a tree increased from 2008 to 2013, then a net increase in growth would be reported. If the volume declined (usually due to mortality), then there would be a net decrease in growth. The total volume change divided by the number of years between measurements yields the average annual net growth on the tree.

What we found

The average annual net growth of live trees on forest land for the 2013 inventory was 398 million cubic feet or roughly 2.1 percent of the total live tree volume in 2013. Growth expressed as a percentage of live tree volume is presented for the 17 most abundant species (by cubic foot volume) in Minnesota in 2013 (Fig. 24). The growth rate for white spruce was the greatest at 4.3 percent; the growth rate for paper birch was -0.7 percent due to high mortality rates.

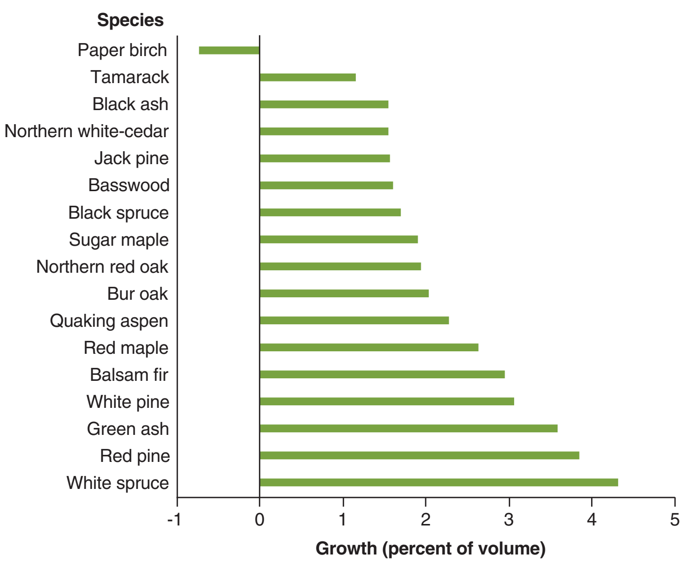


Figure 24.—Average annual net growth of live trees on forest land as a percentage of live tree volume for the 17 most abundant species in Minnesota, 2013.

The average annual net growth rate of live trees on forest land as a percentage of volume varies by landowner class. The rate is highest for private landowners (2.4 percent) followed by state and local governments (2.1 percent), national forests (1.5 percent), and finally other Federal (-0.9 percent). This growth rate also varies by county (Fig. 25). A nonforest mask, derived from the National Land Cover Dataset (NLCD), was placed over the counties so that colored shading would only appear on forested areas where growth may have occurred.

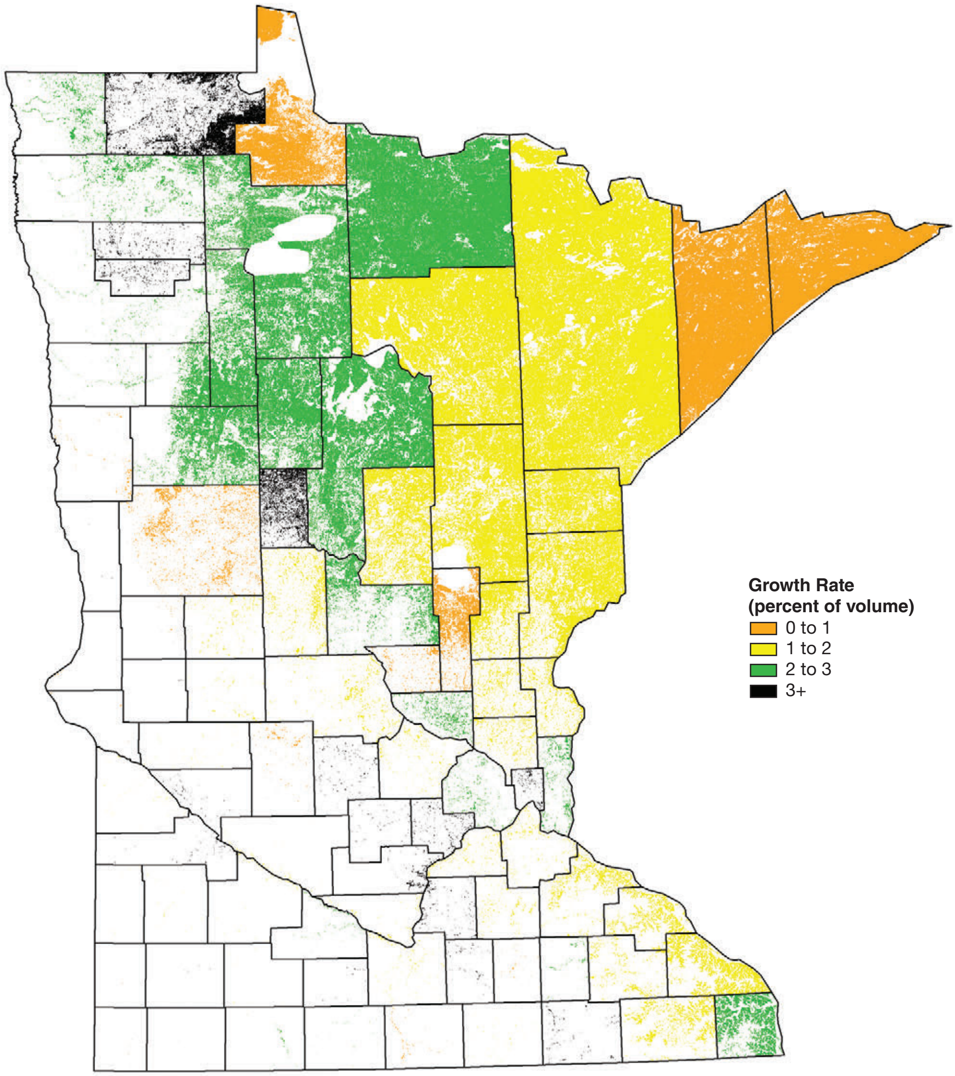


Figure 25.—Average annual net growth of live trees on forest land as a percentage of live tree volume, Minnesota, 2013.

What this means

Growth rates are useful indicators of sustainability, disturbance trends, forest vitality, and direction of succession. But growth provides only one piece of the sustainability puzzle. Information on mortality and removals is also needed to identify the changing composition of the forest. The three change components (growth, mortality, and removals) provide information only on trees 5 inches in diameter and larger. As a result, information on the understory component is not reflected in any of these measures.

Tree Volume Mortality

Background

Mortality occurs as a result of adverse weather, disease, insects (native and exotic), senescence, competition, succession, fire, and human and animal activity. Trees that are killed as a result of harvesting or land clearing are considered removals and are not included in mortality.

What we found

The average annual live tree mortality on forest land for Minnesota in 2013 was 362 million cubic feet or roughly 1.9 percent of the 2013 volume. Mortality expressed as a percentage of volume is presented for the 17 most abundant (by cubic foot volume) species in Minnesota in 2013 (Fig. 26). The mortality rate for balsam fir was the highest at 3.7 percent; the mortality rate for red pine the lowest at 0.2 percent.

The primary cause of mortality could not be determined in 35 percent of the cases. This is not surprising considering that the trees are only revisited every 5 years so a tree could have been dead for up to 5 years when revisited by the field crews, making the call on cause of death problematic.

Among the identifiable primary causes of tree mortality were weather (30 percent), disease (20 percent), insect (10 percent), animal (3 percent), other vegetation (1 percent), and fire (0.3 percent). Although insects were identified as the primary cause of mortality in only a small percentage of cases, they contribute to a much greater share of mortality by weakening trees and making them vulnerable to disease and other forms of attack.

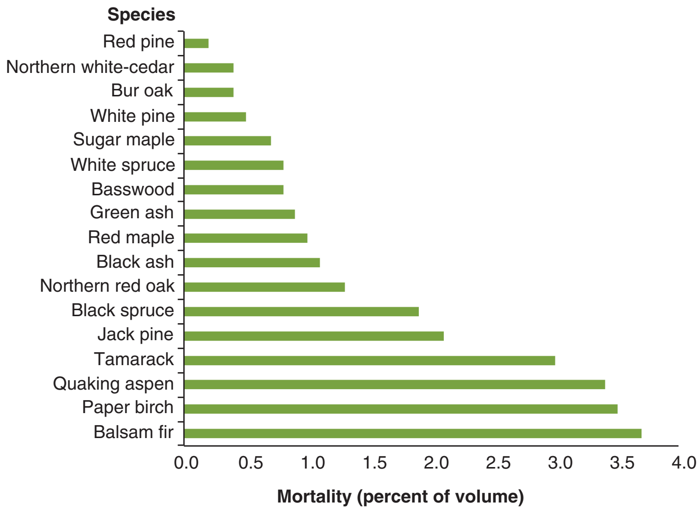


Figure 26.—Average annual live tree mortality on forest land as a percentage of volume for the 17 most abundant species in Minnesota, 2013.

The average annual mortality of live trees on forest land reported in 2013 expressed as a percentage of the 2013 volume is 1.9 percent. The average annual mortality of growing-stock trees on timberland is slightly lower at 1.6 percent of the growing-stock volume on timberland. This is higher than the rate reported for the 1977 inventory (1.2 percent) or for the 1990 inventory (1.3 percent). The rate of 1.6 percent is also higher than the mortality rates for the neighboring states of Iowa (1.5 percent) and Wisconsin (1.1 percent).

The mortality rate of live trees on forest land as a percentage of current live tree volume varies by landowner class. The rate is highest for other federal (2.4 percent) and national forests (2.3 percent), followed by state, county, and local governments (1.9 percent) and private land owners (1.8 percent). The spatial distribution of mortality is presented in Figure 27. A nonforest mask was placed over the counties to more fairly represent the forest area on which mortality would have occurred.

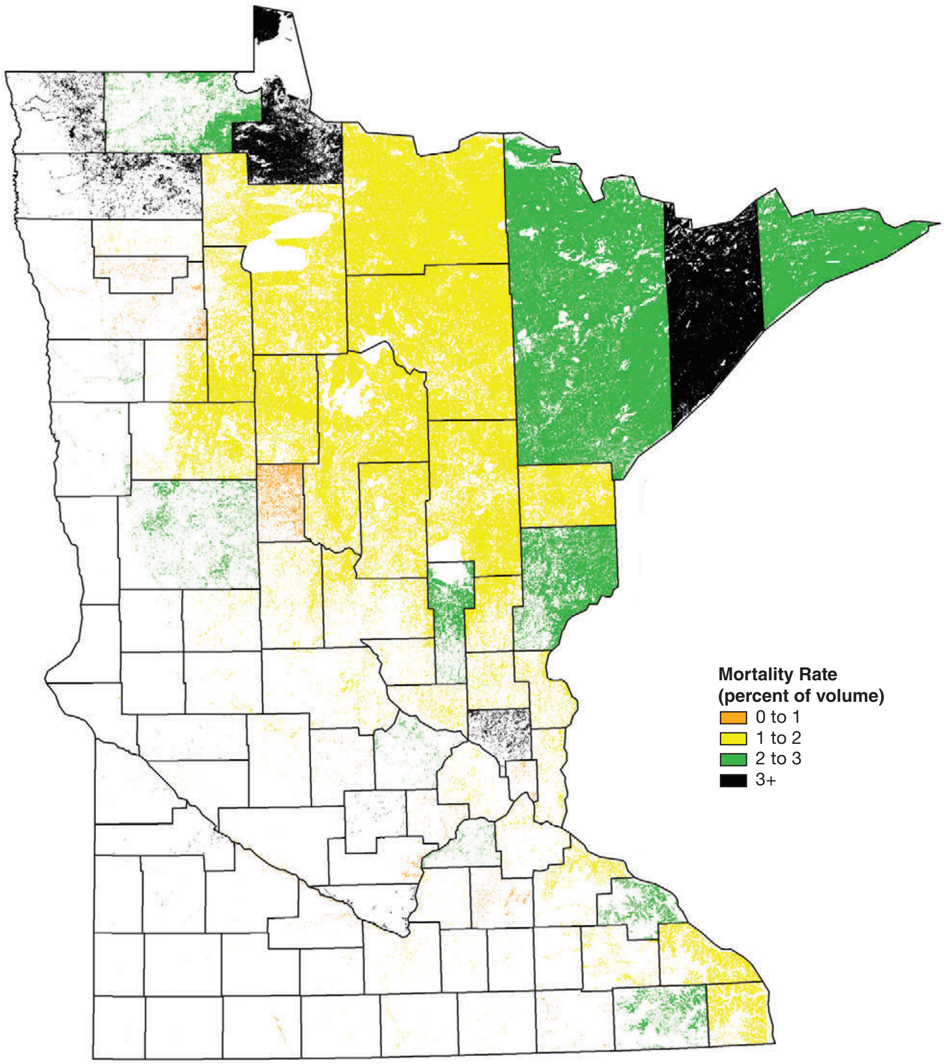


Figure 27.—Average annual live tree mortality on forest land as a percentage of live tree volume, Minnesota, 2013.

What this means

Some of the increase in mortality may be due to the increasing age of Minnesota forests and natural mortality patterns during stand development and succession. Single large weather events also contributed to the increase in mortality.

Tree Volume Removals

Background

There are two types of removals: harvest removals, which include the volume of harvested trees and the volume of trees killed during the harvesting process; and diversion removals, which include the volume of living trees on land previously classified as forest land that has been removed from the forest land base due to land-use change and is now reclassified as nonforest land.

What we found

The average annual live tree removals on forest land for the 2013 inventory of Minnesota was 207 million cubic feet or roughly 1.6 percent of the total tree volume in 2013. This is significantly lower than the 288 million cubic feet reported in 2008. Removals expressed as a percentage of volume is presented for the 17 most abundant (by volume) species in Minnesota in 2013 (Fig. 28). The removals rate for jack pine was the greatest at 2.9 percent while the removals rate for eastern white pine was the lowest at 0.03 percent.

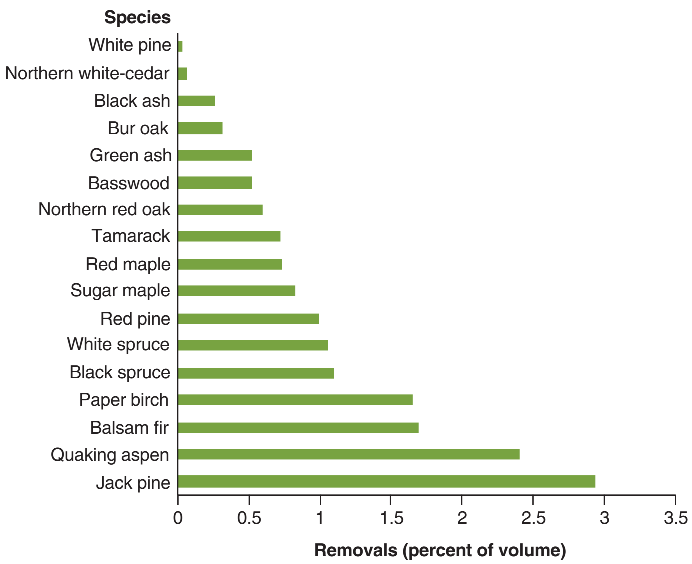


Figure 28.—Average annual removals of live trees on forest land as a percentage of volume for the 17 most abundant species in Minnesota, 2013.

The removals rate as a percentage of volume varies by landowner class. The rate is highest for state and local governments (1.6 percent) followed by private land owners (1.0 percent), national forests (0.4 percent), and finally other Federal (0.3 percent). The spatial distribution of removals is presented in Figure 29. In this graphic, counties were used to plot the rate of removals for Minnesota. A nonforest mask was placed over the counties to more fairly represent the forest area on which removals would have occurred.

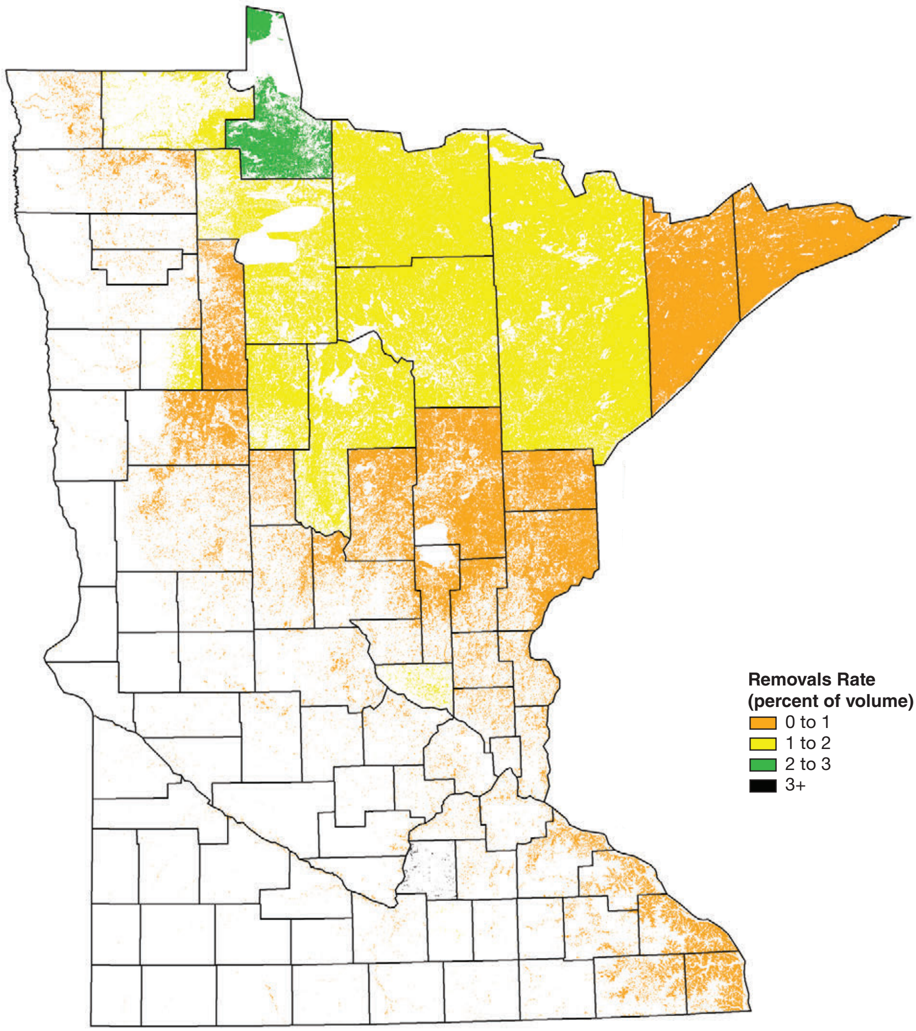


Figure 29.—Average annual live tree removals on forest land as a percentage of live tree volume, Minnesota, 2013.

Most (96 percent) of the removals of live trees from forest land in Minnesota, as measured from FIA field plots during the inventory period, were due to harvesting. Eighty-nine percent of the removals were cut and utilized; 7 percent were killed as a result of the harvesting process and left in the forest (Fig. 30). The remaining 4 percent of removals were due to land-use change where trees were left standing but the land they were on was reclassified by FIA from forest land to nonforest land.

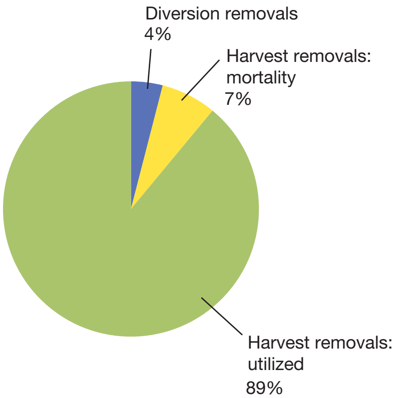


Figure 30.—Average annual growing-stock removals from forest land by disposition of timber, Minnesota, 2013.

What this means

Landowner objectives have a large impact on removal rates. In Minnesota, state and county lands are more actively managed for timber than other public ownerships. Removals rates are highest on state and local government lands and lowest on Federal lands, while per acre sawtimber volumes are highest on Federal lands and lowest on state and local government lands. Likewise corporate ownerships are more actively managed for timber than other private ownerships.

Growth-to-Removals Ratio

Background

One measure of sustainability is the growth-to-removals ratio (G/R), calculated as the net volume growth (gross growth minus mortality) divided by volume removals. A number greater than 1.0 indicates that the volume of the species is increasing.

A number less than 1.0 indicates that the volume is decreasing. This measure is typically applied to lands that were forested at the time of the previous measurement and continue to be forested at the time of the current measurement. This eliminates changes in net growth and removals due to land use-change and focuses on management of lands in the current forest land base.

What we found

Overall, the growth-to-removals ratio of live trees on timberland for the 2013 inventory was 1.7, indicating that overall volume is increasing. By ownership class the growth-to-removals rates are 2.9 for the national forests, 2.3 for private ownership, 1.0 for county and municipal, and 1.3 for state-administered lands. On a species-by-species basis, the picture is less clear, with G/R varying considerable by species (Table 7). Eastern white pine has a G/R of over 65.9; paper birch has a net G/R of -0.3 because mortality exceeds gross growth, resulting in a negative net growth.

Table 7.—Ratio of average annual net growth to average annual removals of live trees (on land classified as timberland in both 2008 and 2013) for the 17 most abundant species (by volume), Minnesota, 2013

Species	Net growth-to-removals ratio	Net growth	Removals	Live tree volume on timberland
		------------------ *Million ft³*	------------------	
Eastern white pine	65.9	13.1	0.2	428.9
Northern white-cedar	23.0	16.2	0.7	1102.1
Bur oak	6.9	16.6	2.4	1023.6
Black ash	5.1	11.4	2.2	961.3
Green ash	4.3	9.5	2.2	454.3
Northern red oak	4.2	13.7	3.3	868.7
Red pine	3.7	42.1	11.5	1144.6
American basswood	3.5	12.7	3.6	948.1
White spruce	3.3	14.1	4.3	388.5
Red maple	3.1	13.8	4.4	569.4
Sugar maple	2.1	11.0	5.2	665.3
Black spruce	1.5	15.4	10.0	804.5
Balsam fir	1.4	16.3	11.5	660.0
Tamarack (native)	1.1	5.8	5.1	695.2
Quaking aspen	1.1	80.8	76.6	3250.5
Jack pine	0.5	5.3	11.3	305.9
Paper birch	-0.3	-4.7	16.5	968.4

The average annual removals of live trees on timberland reported for the 2013 inventory (210 million cubic feet) was lower than the 303 million cubic feet reported for the 2008 inventory. Harvest removals of live trees on timberland were estimated at 197 million cubic feet in 2013, a 29 percent decrease from the 277 million cubic feet of harvest removals for the period ending in 2008. Of the three components of change (growth, removals, and mortality), removals is the most directly tied to human activity and is thus the most responsive to changing economic conditions.

What this means

Insect infestations, disease, and succession can result in low G/R ratios. Paper birch had a negative G/R because its mortality exceeded gross growth over the period. Net growth is equal to gross growth less mortality.

A G/R of less than 1.0 is sometimes needed to achieve management goals. Sometimes it is necessary to manage the forest so that a species will temporarily have a G/R ratio of less than 1.0. When short-lived species such as quaking aspen are nearing senescence, for example, it may make sense to try to "capture mortality" (harvest a tree before it dies of old age).

Health Indicators

Pagami Creek Fire, 2 years later (taken August 2013). Photo by Eli Sagor, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

Regeneration Status

Background

The composition and abundance of tree seedlings drives stand development and sets the stage for future composition and structure. Forest systems of Minnesota face a number of regeneration stressors (e.g., invasive plants, insects, diseases, climate change, and herbivory). As stands that make up these systems mature and undergo stand replacement disturbances, it is imperative to know the condition of the regeneration component. In most situations, establishing desirable reproduction is the key to developing stands with high-canopy species that meet manager's objectives. Tending of young stands to control composition and stocking levels is also an important consideration (Johnson et al. 2002, Smith et al. 1997). Regeneration data are critically important for understanding and projecting future forest character that ultimately determines sustainability of the full suite of forest values available from Minnesota forests.

Early successional young forest habitat provides unique plant biota and landscape heterogeneity (Greenberg et al. 2011). Minnesota forests supports many birds and mammals which depend on young forest habitat. Some prime examples include golden-winged warbler (*Vermivora chrysoptera*), American Woodcock (*Scolopax minor*), and cottontail rabbit (*Sylvilagus floridanus*) (Gilbart 2012). The vitality of young forest depends directly on the condition of the regeneration component.

To fill the need for more detailed information on regeneration, the Northern Research Station's Forest Inventory and Analysis program added protocols for data to be collected on a subset of sample plots measured during the growing season (McWilliams et al. 2015). The results in this report are based on data collected from 151 sample plots measured in 2012 and 2013. The procedures measure all established tree seedlings less than 1 inch in diameter at breast height (d.b.h.) by length class and include a browse impact assessment for the area surrounding the sample location. The regeneration indicator data improve NRS-FIA's ability to evaluate this important aspect of forest health and sustainability.

What we found

As Minnesota forest stands continue to age, young forest is becoming rare as older, more mature stands are increasing. Since 1977, the area of young forest (0-20 years old) decreased from about one-third of Minnesota forest land to 18 percent. The aspen/birch forest-type group covers 37 percent of the State's forest land and accounts for 60 percent of the young forest. All of the other major groups make up less than 10 percent of the young forest, except for the white/red/jack pine forest-type group that makes up 13 percent.

Results of the browse impact assessment show that most of the samples had low (54 percent) or medium (35 percent) levels of browse of understory plants (Fig. 31). Only 11 percent had high browse levels. Examination of browse impact across the State (Fig. 32) reveals that most of the samples with medium or higher levels of browse impact are randomly distributed.

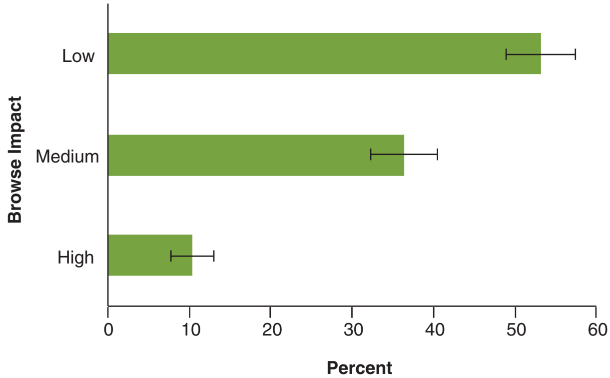
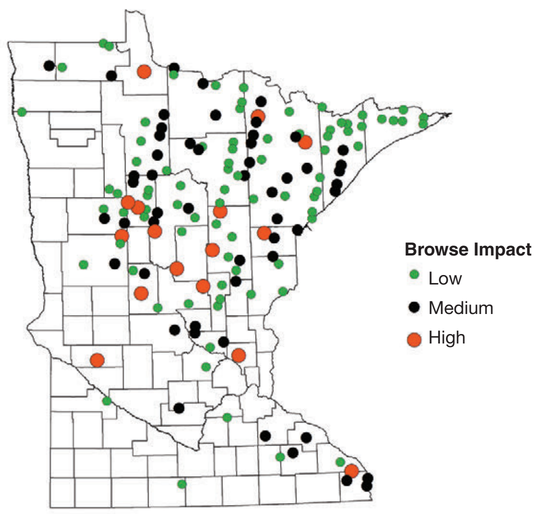


Figure 31.—Browse impact on forested P2+ samples, Minnesota, 2012-2013. Error bars represent a 68 percent confidence interval around the estimated mean.



(Plot locations are approximate)

Figure 32.—Distribution of forested P2+ samples on forest land by browse impact, Minnesota, 2012-2013.

The total number of seedlings is estimated at 106.3 billion, or a state-wide average of 5,700 seedlings per acre. Forty seven percent of the seedlings are less than 1 foot tall, 41 percent are 1.0 to 4.9 feet, and 12 percent are 5.0 feet and taller (Fig. 33). Seedling abundance most likely reflects the pattern of disturbance. Given the small sample size, seedling abundance exhibits no readily apparent geographic pattern across Minnesota (Fig. 34).

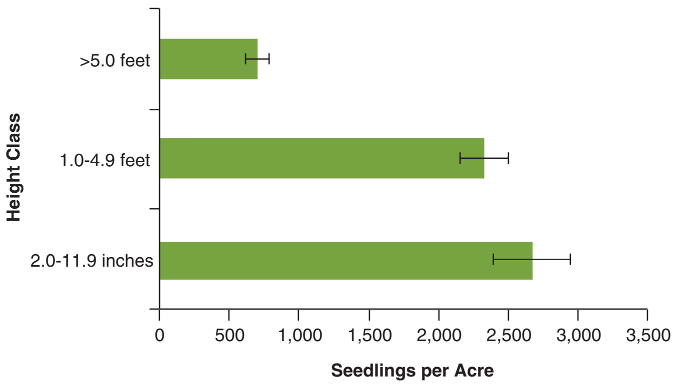
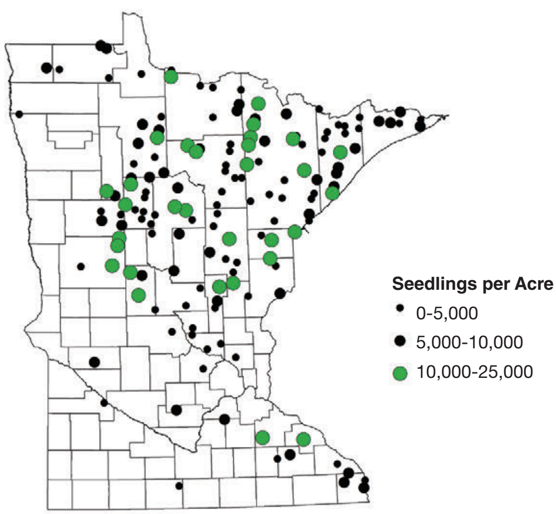


Figure 33.—Average number of seedlings per acre on forest land by height class, Minnesota, 2012-2013. Error bars represent a 68 percent confidence interval around the estimated mean.



(Plot locations are approximate)

Figure 34.—Distribution of forested P2+ samples on forest land by number of seedlings per acre, Minnesota, 2012-2013.

In total number, 42 species/species groups have been encountered by the regeneration indicator samples so far. Maple and ash are the most abundant genera, accounting for 22 and 18 percent of the total number of seedlings, respectively. Sugar maple is the most prominent species, with 10 percent of the seedlings (Fig. 35). Most of the other species with at least 1 percent of the seedling pool were species capable of developing as canopy dominants under favorable conditions.

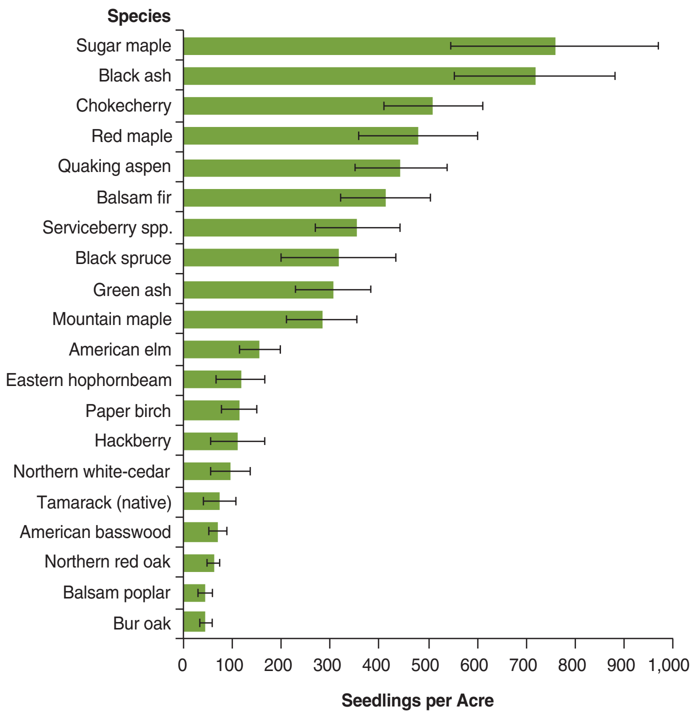


Figure 35.—Average number of seedlings per acre on forest land for all species with at least 1 percent of the total number of seedlings, Minnesota, 2012-2013. Error bars represent a 68 percent confidence interval around the estimated mean.

Comparing species abundance using the percentage of the total number of trees by height and diameter class highlights potential pathways for future canopy dominants. Figure 36 depicts results for select species/species groups for seedlings, dominant/codominant saplings, and adults based on the percentage each contribute to the total for each size class. Prospective "gainers" are those species with relatively high percentages of stems in the regeneration pool of seedlings and saplings compared to larger trees. The aspens, maples, ashes, balsam fir, and the "other" species group are the most apparent gainers. Expectations for the ashes should be tempered with information on the prospective demise of ash due to impacts of the emerald ash borer. Prospective "losers" in the process of developing future canopy dominants are species with lower percentages in the regeneration pool than the adult pool. Potential losers are the red oaks, white oaks, spruces (mostly black spruce), and red pine. 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.

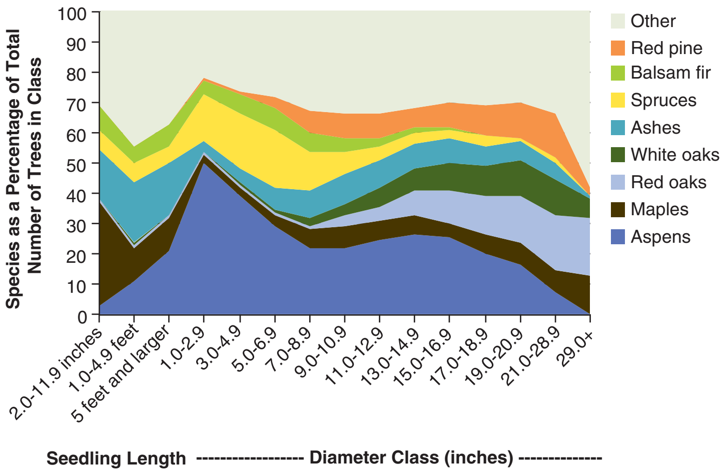


Figure 36.—Species composition for seedlings, dominant/codominant live saplings, and growing-stock trees on forest land for species with the greatest aboveground biomass, Minnesota. Seedling estimates are for 2012-2013 and sapling and tree estimates are for 2009-2013.

What this means

Minnesota forests face a variety of forest health risks, and tree reproduction is an integral factor for ameliorating most of them during the early phases of forest development. Some prominent examples are competition from invasive plants, insects and diseases, and forest fragmentation.

Deer browse is a major factor affecting regeneration in the eastern United States (Russell et al. 2001, White 2012), but in Minnesota, browse levels are not as high as some other states. Still, the finding that nearly half of the regeneration indicator samples measured had at least medium browse impact is an indication that browsing is having an effect. 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 that occurs more frequently in the more populated areas of the State (Augustine and deCalesta 2003).

The most noteworthy regeneration issue found in the results is a general lack of young oak seedlings and saplings. Oak/hickory and oak/pine forests compose nearly 15 percent of Minnesota forest land and are vital for both timber and wildlife. Oak regeneration is a common problem in the eastern United States, and management challenges, such as lack of fire and herbivory, have been described (Holt and Fischer 1979). 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 shade tolerant species such as sugar and red maple (Abrams 1992).

Black spruce and red pine are other species that do not have an abundance of reproduction based on measurements to date. The situation for these species is not as dire as for the oaks. Although relatively few black spruce seedlings were found, the distribution of stems by size class shows an abundance of saplings and young adult stems. The red pine distribution lacks both seedlings and saplings but has an abundance of young adults and a spike in the number of stems in the 18-inch d.b.h. and larger classes. This means that the older red pine stands will eventually need to be replaced. Both black spruce and red pine are commonly established by planting, direct seeding, and density management to ensure maintenance over the long term. Palik and Johnson (2007) provide a thorough discussion of constraints on pine regeneration.

Eventually, most forest stands will experience either anthropogenic or natural stand replacement events, such as mortality or harvest, and require regeneration to establish new forest. Clearly, forest regeneration will be the key to successful establishment of healthy young forests. Management options for establishing regeneration of palatable species will also be driven by the amount of browse.

The results presented here for Minnesota reflect only two of the five panels of measurements that will eventually compose the first full baseline dataset for the regeneration indicator. Barring any extension of the inventory cycle length, the next 5-year inventory report for Minnesota will have a complete dataset. This will facilitate more detailed analyses (e.g., more 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 Minnesota forests.

Tree Crown Health and Tree Damage

Background

The crown condition of trees is influenced by various biotic and abiotic stressors. Abiotic stressors include drought, flooding, cold temperatures or freeze injury, nutrient deficiencies, soil physical properties that affect soil moisture and aeration, or toxic pollutants. Biotic stressors include native or introduced insects, diseases, invasive plant species, and animals.

Exotic diseases and insects are important threats to the productivity and stability of forest ecosystems around the world (Liebhold et al. 1995a, Pimentel et al. 2000, Vitousek et al. 1996). Over the last century, Minnesota forests have suffered the effects of native insect pests such as spruce budworm (*Choristoneura fumiferana Clemens*) and the well-known exotic and invasive agent Dutch elm disease (*Ophiostoma ulmi*) among many others. More recently, invasions by the emerald ash borer (*Agrilus planipennis*) and European gypsy moth (*Lymantria dispar*) are threatening the health of trees. Additionally, although Asian longhorned beetle (*Anoplophora glabripennis*), mountain pine beetle (*Dendroctonus ponderosae*), and thousand cankers disease have not yet been discovered in Minnesota, they are emerging threats that have been confirmed in nearby states.

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

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

What we found

The incidence of poor crown condition is low across Minnesota with no discernable spatial pattern (Fig. 37). Currently the only species with more than 5 percent of live basal area containing poor crowns is paper birch (Table 8). Plots with greater than 5 percent of paper birch basal area containing poor crowns are indicated by the orange dots in Figure 38. Mean dieback ranged from less than 1 percent for red pine and black spruce to 5.8 percent for northern white-cedar (Table 9).

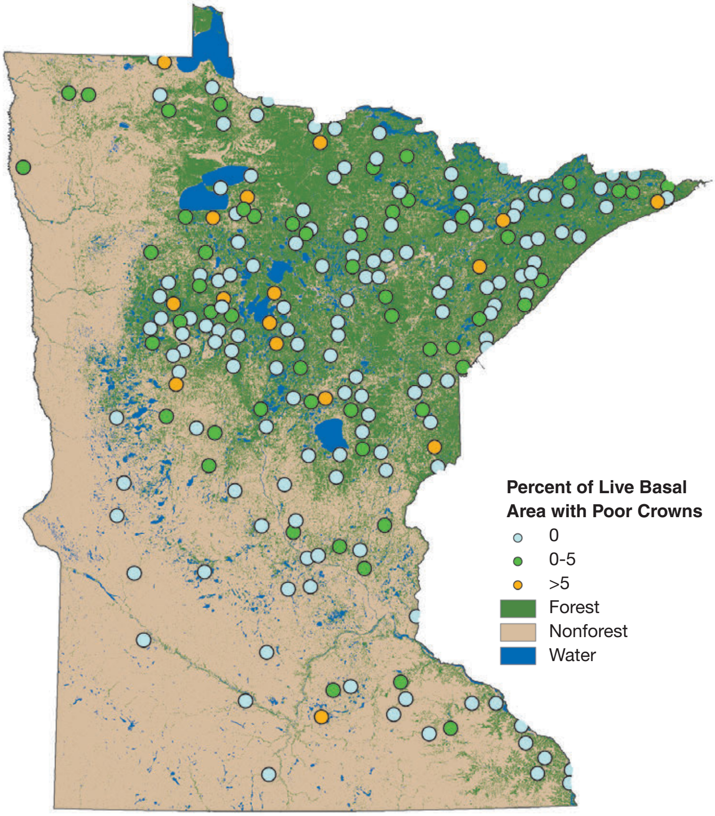


Figure 37.—Plot location and percentage of live basal area for all species with poor crowns, Minnesota, 2013. Depicted plot locations are approximate.

Table 8.—Percent of live basal area with poor crowns by species and inventory year, Minnesota

Species	2008	2013
	---------------------- *Percent*	--------------------
Paper birch	5.7	7.6
Northern white-cedar	7.2	4.6
Quaking aspen	4.1	3.6
Black ash	10.9	3.0
Northern red oak	6.3	2.2
Balsam fir	0.4	1.7
Bur oak	2.1	1.1
Black spruce	2.6	0.3
American basswood	2.3	0.2
Red pine	0.0	0.0

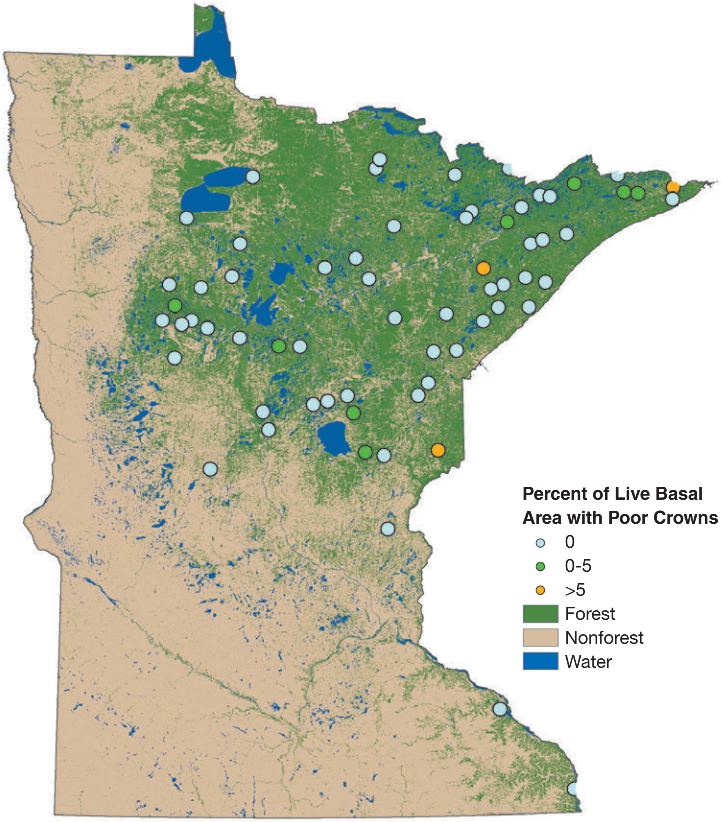


Figure 38.—Plot location and percentage of live basal area for paper birch with poor crowns, Minnesota, 2013. Depicted plot locations are approximate.

Table 9.—Mean crown dieback and other statistics for live trees (>5 inches d.b.h.) on forest land by species, Minnesota, 2013

Species	Number of trees	Mean	SE	Minimum	Median	Maximum
		Percent				
Northern white-cedar	390	5.8	0.78	0	0	99
Northern red oak	170	4.9	0.52	0	5	60
Paper birch	233	4.1	0.68	0	0	99
Black ash	190	4.1	0.71	0	0	65
American basswood	175	3.3	0.58	0	0	95
Bur oak	252	3.2	0.30	0	5	40
Quaking aspen	902	2.2	0.26	0	0	95
Balsam fir	230	1.0	0.20	0	0	25
Black spruce	343	0.8	0.14	0	0	25
Red pine	199	0.3	0.08	0	0	5

Figure 39 shows the proportion of remeasured trees that survived, died, or were cut in each crown dieback class based on the health of the crowns at the previous measurement. The proportion of trees that die increases with increasing crown dieback. Nearly 40 percent of trees with crown dieback above 20 percent during the 2008 inventory were dead when visited again during the 2013 inventory.

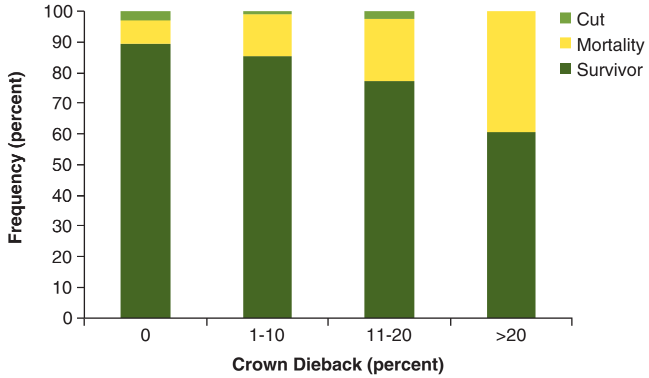


Figure 39.—Crown dieback distribution by tree survivorship for remeasured trees, Minnesota, 2008 to 2013.

Tree damage was recorded on approximately 25 percent of the trees in Minnesota, but there is considerable variation between species. The most frequently recorded damage was decay, which was present in 17 percent of the trees and ranged from 3 percent on red pine and black spruce to 27 percent on northern red oak. Decay was also recorded on more than 15 percent of paper birch, American basswood, quaking aspen, and northern white-cedar trees. Cankers were present on 8 percent of quaking aspen trees, animal damage was recorded on 7 percent of bur oak trees, and weather damage was observed on more than 5 percent of northern white-cedar, paper birch, and black ash trees. The occurrence of all other injury types was very low (Table 10).

Table 10.—Percent of trees with damage by species, Minnesota, 2013

	Damage type							
Species	None	Animal	Cankers	Decay	Insect damage	Logging/ human	Other	Weather
All	75	3	2	17	2	1	2	4
American basswood	74	6	1	16	2	1	2	5
Balsam fir	85	3	0	7	4	1	2	3
Black ash	78	1	0	12	1	1	3	9
Black spruce	91	1	0	3	1	0	3	2
Bur oak	79	7	0	11	1	2	2	2
Northern red oak	68	3	1	27	1	1	2	5
Northern white-cedar	70	2	0	23	0	0	2	8
Paper birch	72	3	1	15	4	1	3	8
Quaking aspen	70	1	8	22	4	0	1	2
Red pine	93	2	0	3	1	2	0	0

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

What this means

The trees of most important species in the forests of Minnesota are generally in good health, but substantial dieback was observed on paper birch. The cause of poor crown health in paper birch is likely due to senescence. Paper birch also has one of the highest mortality rates of all species in the State (Fig. 26). The health of tree crowns in ash species, oak species, maple species, black walnut, and butternut should be monitored closely due to recent and likely future invasions by emerald ash borer, gypsy moth, Asian longhorned beetle, and thousand cankers disease (see subsequent sections).

Decay was the most commonly observed type of damage which is not unusual given that the majority of Minnesota forests are large and medium diameter stands composed of mature trees. The incidence of cankers on quaking aspen is due to Hypoxylon canker, caused by the fungus *Hypoxylon mammatum* (Wahl.), which is one of the most important killing diseases of aspen in eastern North America (Anderson et al. 1979).

Exotic Forest Insects and Pathogens

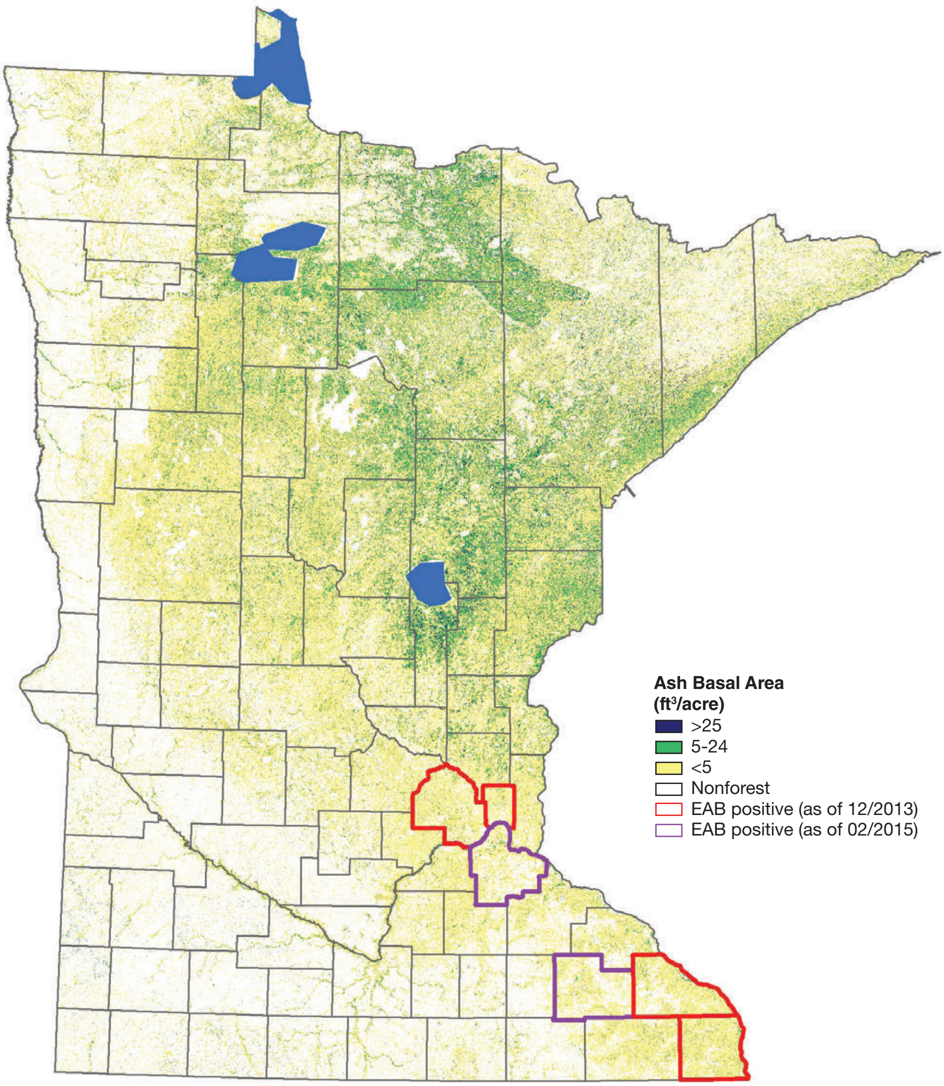
Background

The introduction and establishment of exotic insects and pathogens can have significant impacts on the structure and composition of native forest ecosystems due to a lack of natural enemies and plant host defenses. Therefore, monitoring the status and impacts of these organisms is crucial to assessments of forest health (Jules et al. 2002, Poland and Haack 2003, Work et al. 2005). A number of exotic insects and pathogens were active during the inventory period. Two of the more significant insects are emerald ash borer (*Agrilus planipennis;* EAB) and the European gypsy moth (*Lymantria dispar*). EAB was first detected in the United States in 2002 and has been present in Minnesota since 2009. It is a wood-boring pest of all North American ash. European gypsy moth continues to spread west across the United States into eastern Minnesota. Tree species were split into preferred and nonpreferred suitability classes based on field and laboratory tests by Liebhold et al. (1995b). Species in suitability class 1 were considered preferred and all others were considered nonpreferred.

What we found

Emerald ash borer

There are 1.1 billion ash trees in Minnesota that are at least 1-inch d.b.h. or larger. Ash makes up 8 percent of all trees and is well distributed across the State with the highest concentrations in northern and central Minnesota (Fig. 40). Ash growing-stock mortality on timberland was relatively stable between 1977 and 2003; however mortality doubled over the past 10 years, reaching 11.0 million cubic feet per year, nearly 5 percent of total mortality, in 2013. The rate of ash mortality as a percentage of live ash tree volume on forest land is 1.0 percent compared to 2.0 percent for all other species. The majority of ash mortality was concentrated in the northcentral part of the State, and therefore mortality was not the result of emerald ash borer.



Processing note: This map was produced by linking plot data to MODIS satellite pixels (205 m) using gradient nearest neighbor techniques.

Figure 40.—Ash density on forest land, Minnesota, 2013, and counties positive for emerald ash borer.

Gypsy moth

Approximately 48 percent of the live tree volume in Minnesota includes species preferred by gypsy moth. The most abundant preferred species in the State are quaking aspen, paper birch, and the oaks. The density of preferred gypsy moth host species is highest in the western half of northern Minnesota (Fig. 41). In July of 2014, a quarantine that restricts intrastate movement of material that may spread this invasive pest was implemented in Cook and Lake Counties (Minnesota Department of Agriculture 2015).

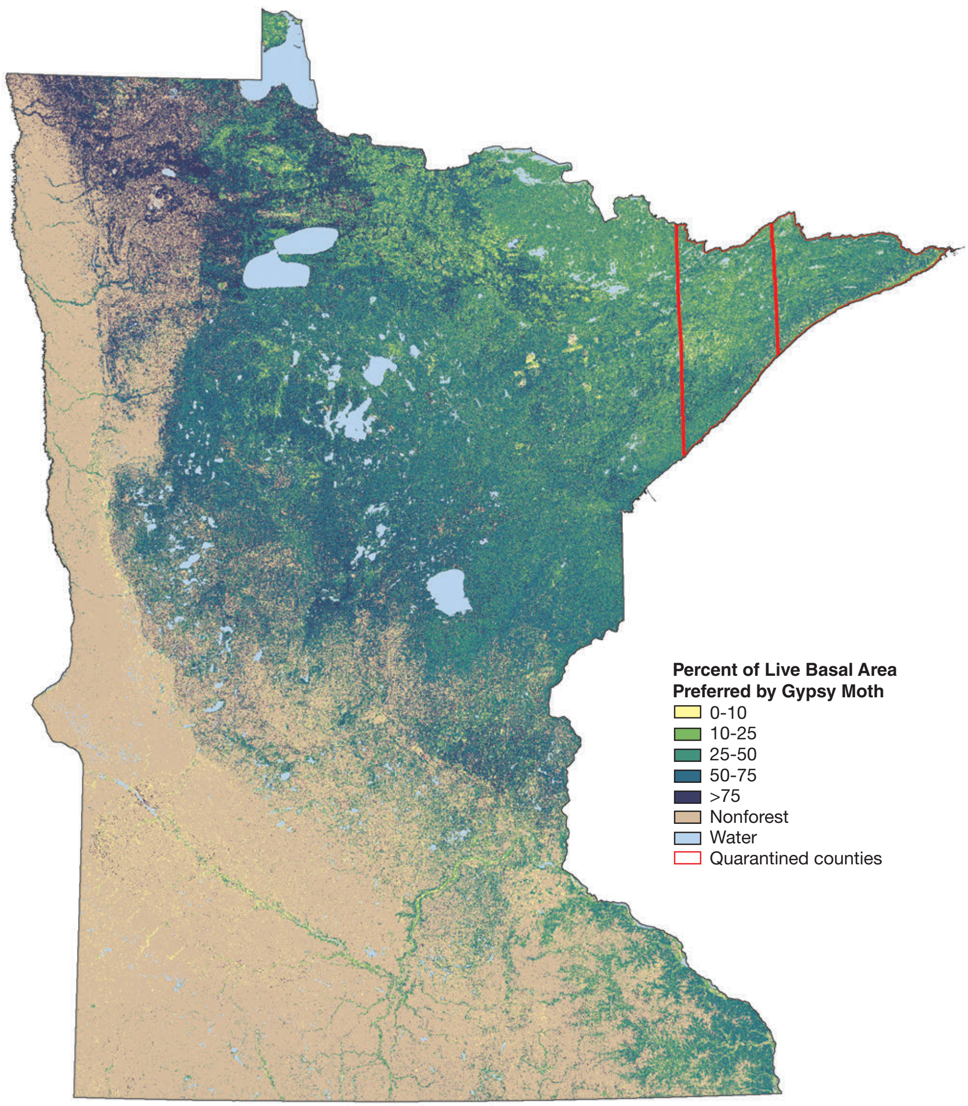


Figure 41.—Basal area of gypsy moth preferred trees and quarantined counties, Minnesota, 2013.

What this means

Emerald ash borer

Rising mortality over the past decade and a relatively high mortality rate are indications of declining ash health statewide. Ash decline is likely an important contributor to ash mortality, particularly in the north. Mortality due to EAB is expected to increase as EAB spreads into forested areas with higher densities of ash. Therefore, continued spread of EAB could have a considerable impact on ash health and the future composition of Minnesota forests.

Gypsy moth

The forests of Minnesota have not been impacted by gypsy moth as of yet, but moths have been captured as part of the Gypsy Moth Slow the Spread program. Quantification of the amount of the forest resource that is preferred by the gypsy moth can help land managers prepare for future outbreaks. Minnesota will likely need to consider suppression activities to reduce the impacts of defoliation in future years as gypsy moth populations continue to spread into the State.

Invasives

Background

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

What we found

To aid in monitoring these species, FIA assessed the presence of 39 IPS and one undifferentiated genus (nonnative bush honeysuckles)[2] on 888 forested P2 invasive plots in Minnesota from 2009-2013. Of the 40 invasives monitored (Table 11), 17 were observed. Reed canarygrass was the most commonly observed species (164 plots; 18.5 percent of the forested P2 invasive plots) and was found throughout the State. Nonnative bush honeysuckles (110 plots) and common buckthorn (96 plots) were the next most commonly observed species and occurred on more than 10.0 percent of plots. Six of the 17 IPS observed were found on 1.0 percent or more of the plots, with 37.8 percent of the plots having one or more of the monitored IPS.

The number of IPS per forested plot ranged from 0 to 5 (Fig. 42). The distribution of the plots where invasive plants were present is fairly homogeneous throughout the state (Fig. 43), with the southern plots having a larger number of invasive plant species. When reviewing these figures it is important to remember that the inventory is of forested areas, so less forested areas have fewer plots. On average, plots with invasive species were closer to roads (1,700 feet versus 5,100 feet for plots without invasive species), had fewer 5 inches d.b.h. and larger trees per acre (137 versus 155), and fewer 1-inch d.b.h and larger trees per acre (650 versus 840).

Figure 44 shows the location of common buckthorn in Minnesota based on forested P2 invasive plots. In Minnesota common buckthorn was found primarily in riparian areas and the Eastern Broadleaf Ecoregion Province. Buckthorn is widely dispersed by birds and mice feeding on its fruit.

In the 2008 report for Minnesota (Miles et al. 2011), the invasive plant data was based on the Phase 3 vegetation plots whereas in this report the data is based on the P2 invasive data. There was a slight increase from the last inventory in the number of plots with invasive species present. In addition, there was an increase in the presence of common buckthorn and Canada thistle which occurred on 10.8 and 9.2 percent of plots, respectively, in 2013. In 2008, common buckthorn was found on approximately 9.2 percent of plots and Canada thistle was observed on 1.6 percent of plots. In addition, multiflora rose was not recorded in the 2008 inventory but was found on 4 plots in 2013. Over time it will be important to monitor the percentage of plots where these species are observed as well as to watch for the presence of new invasive species.

---

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

Table 11.—The 39 invasive plant species and one undifferentiated genus monitored on NRS-FIA P2 invasive plots and observances, 2007 to 2013

Tree Species	Observances	Percentage of plots
Black locust (*Robinia pseudoacacia*)		
Chinaberry (*Melia azedarach*)		
Norway maple (*Acer platanoides*)		
Princesstree (*Paulownia tomentosa*)		
Punktree (*Melaleuca quinquenervia*)		
Russian olive (*Elaeagnus angustifolia*)		
Saltcedar (*Tamarix ramosissima*)		
Siberian elm (*Ulmus pumila*)	5	0.5
Silktree (*Albizia julibrissin*)		
Tallow tree (*Triadica sebifera*)		
Tree-of-heaven (*Ailanthus altissima*)		
Woody Species		
Autumn olive (*Elaeagnus umbellata*)		
Common barberry (*Berberis vulgaris*)		
Common buckthorn (*Rhamnus cathartica*)	96	10.5
European cranberrybush (*Viburnum opulus*)	1	0.1
European privet (*Ligustrum vulgare*)		
Glossy buckthorn (*Frangula alnus*)	12	1.3
Japanese barberry (*Berberis thunbergii*)	6	0.7
Japanese meadowsweet (*Spiraea japonica*)		
Multiflora rose (*Rosa multiflora*)	4	0.4
Nonnative bush honeysuckles (*Lonicera* spp.)	110	12.4
Vine Species		
English ivy (*Hedera helix*)		
Japanese honeysuckle (*Lonicera japonica*)	1	0.1
Oriental bittersweet (*Celastrus orbiculatus*)		
Herbaceous Species		
Black swallow-wort (*Cynanchum louiseae*)		
Bohemian knotweed (*Polygonum xbohemicum*)		
Bull thistle (*Cirsium vulgare*)	40	4.4
Canada thistle (*Cirsium arvense*)	82	9.2
Creeping jenny (*Lysimachia nummularia*)	2	0.2
Dames rocket (*Hesperis matronalis*)		
European swallow-wort (*Cynanchum rossicum*)		
Garlic mustard (*Alliaria petiolata*)	6	0.7
Giant knotweed (*Polygonum sachalinense*)		
Japanese knotweed (*Polygonum cuspidatum*)		
Leafy spurge (*Euphorbia esula*)	1	0.1
Purple loosestrife (*Lythrum salicaria*)	1	0.1
Spotted knapweed (*Centaurea stoebe* ssp. *micranthos*)	5	0.5
Grass Species		
Common reed (*Phragmites australis*)	1	0.1
Nepalese browntop (*Microstegium vimineum*)		
Reed canarygrass (*Phalaris arundinacea*)	164	18.5

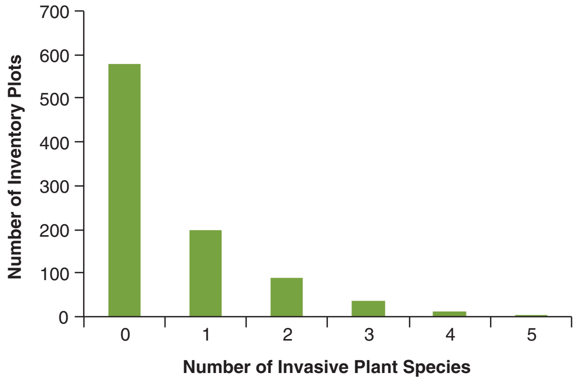
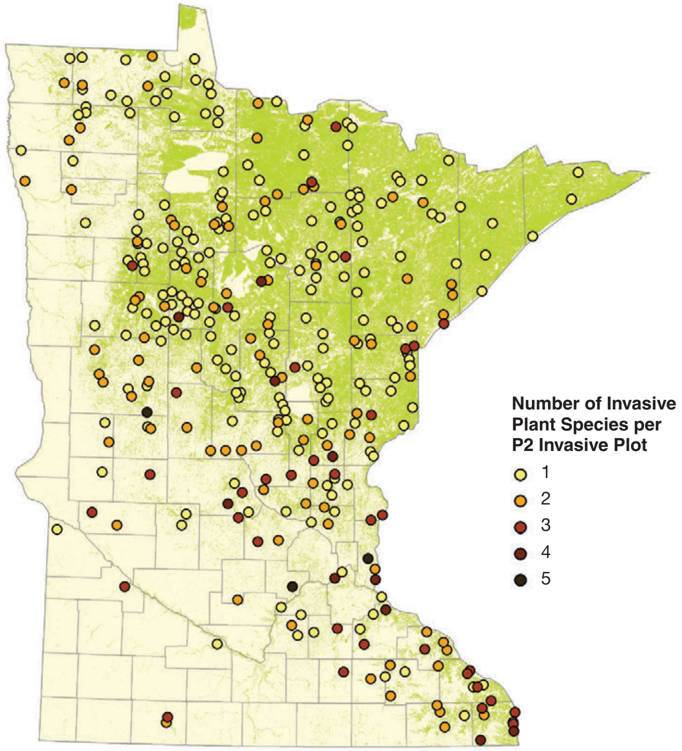
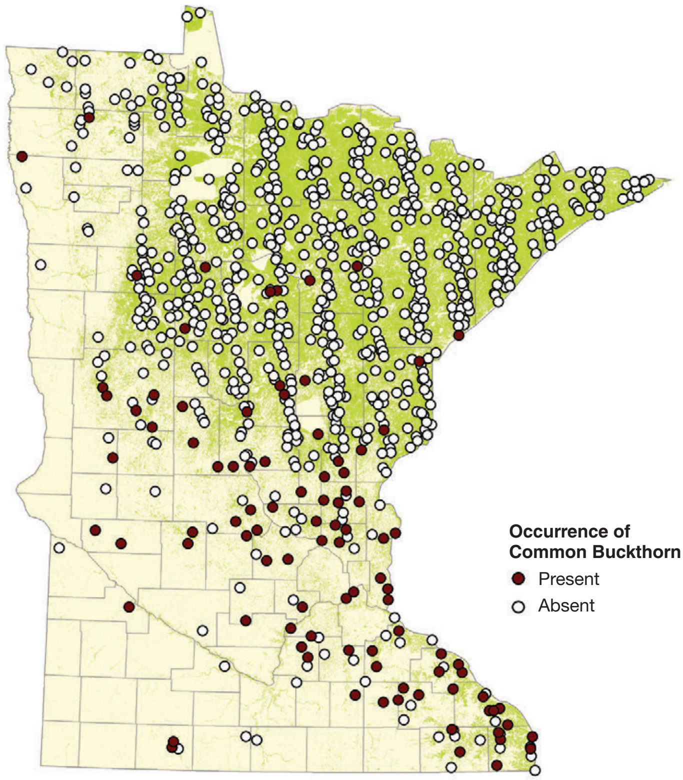


Figure 42.—Number of invasive plant species per forested P2 Invasive plot, Minnesota, 2013.



Projection: NAD83, UTM Zone 15N.
Data Source: USDA Forest Service Forest Inventory and Analysis Program 2009-2013 P2 Invasive data; State and county layers source: ESRI Data and Maps 10.1. Forest/nonforest source: NLCD 2006.
Depicted plot locations are approximate. Cartography: C.M. Kurtz. January 2015

Figure 43.—Number of invasive plant species observed on forested FIA P2 Invasive plots, Minnesota, 2013.



Projection: NAD83, UTM Zone 15N.
Data Source: USDA Forest Service Forest Inventory and Analysis Program 2009-2013 P2 Invasive data; State and county layers source: ESRI Data and Maps 10.1. Forest/nonforest source: NLCD 2006. Depicted plot locations are approximate. Cartography: C.M. Kurtz. January 2015

Figure 44.—Distribution of common buckthorn on forested FIA P2 Invasive plots, Minnesota, 2013.

What this means

Minnesota forests had a lower percentage of forested plots invaded (37.8 percent) than neighboring Iowa where 94.4 percent of forested plots had one or more of the monitored invasive plant species. Minnesota likely has less invasives within its forests due to its settlement history and lower fragmentation than neighboring states. However, the presence of IPS within Minnesota forests is still of major and increasing concern, and it is important that these species are monitored over time to ensure that managers and the general public are aware of their occurrence and spread. Areas of higher fragmentation, such as southern Minnesota, are of particular concern due to number of invasives currently observed on the plots.

Invasive plants are good competitors and able to alter forested ecosystems by displacing native species and impacting the fauna that depend upon them. Several factors contribute to their success, such as prolific seed production, ability to propagate vegetatively, rapid growth rate, and ability to survive in harsh conditions. Many factors contribute to forest invasion, including ungulates, development, fragmentation, and timber harvesting. Invasive plants can negatively affect the carbon budget by reducing future tree cover. Furthermore, these species can cause negative economic implications by reducing timber yield and aesthetic beauty. Further investigation of the inventory data may help to reveal influential site and regional trends.

Down Woody Materials

Background

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

What we found

The total carbon stored in down woody materials (fine and coarse woody debris and residue piles) on Minnesota forest land was nearly 53 million short tons (Fig. 45). Downed woody debris carbon was unequally distributed by stand-age class with moderately aged stands (61 to 80 years) having the highest total carbon (~23 million tons). The downed dead wood biomass within Minnesota forests is dominated by coarse woody debris (Fig. 46) at approximately 67 million short tons with piles only representing 8 percent of statewide totals. The total volume of coarse woody debris was highest on private forest land at approximately 3.4 billion cubic feet (Fig. 47). State and local forests had the second largest totals of coarse woody debris volume (2.4 billion cubic feet). Privately owned lands have the highest volumes of dead wood in piles at over 600 million cubic feet.

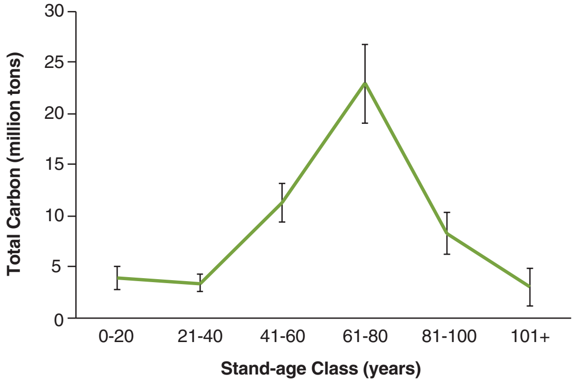


Figure 45.—Total carbon in down woody materials (fine and coarse woody debris and piles) by stand-age class on forest land, Minnesota, 2006-2010. Error bars represent a 68 percent confidence interval around the estimated mean.

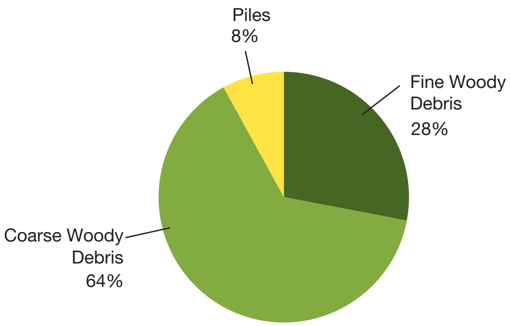


Figure 46.—Percentage of dead wood biomass on forest land by component (fine and coarse woody debris and residue piles), Minnesota, 2006-2010.

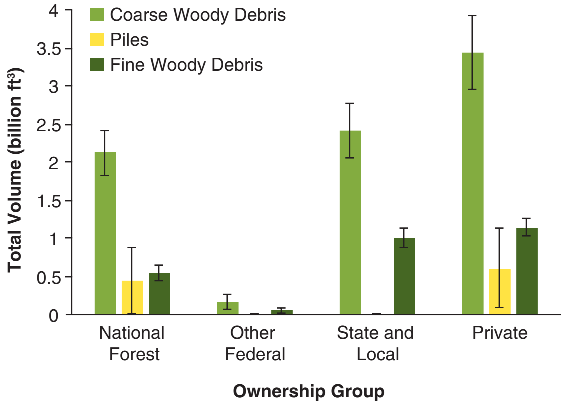


Figure 47.—Total volume of coarse woody debris and deadwood piles on forest land by ownership group, Minnesota, 2006-2010. Error bars represent a 68 percent confidence interval around the estimated mean.

What this means

Given the relatively moist temperate forests across Minnesota, the biomass within down woody materials would only be considered a fire hazard during times of drought. Although the carbon stocks of down woody materials are relatively small compared to those of soils and standing live biomass, down woody materials are still a critical component of the carbon cycle as a transitory stage between live biomass and other detrital pools such as litter. If future temperature and precipitation patterns change, there is a potential for a reduction in down woody material 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 states where there is more pervasive industrial management of forests (Woodall et al. 2013), there were relatively few residue piles sampled in this first down woody materials inventory of Minnesota forests. Given that the vast majority of coarse woody debris volume was estimated to be in private ownership, it is the management of Minnesota private forests that may most affect the future of down woody material contributions to statewide forest carbon stocks and wildlife habitat (i.e., stand structure). Overall, because estimates of fuel loadings are not exceedingly high across Minnesota, possible fire dangers may be outweighed by the numerous ecosystem services provided by down woody materials.

Forest Carbon

Background

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 climate change. Among terrestrial ecosystems, forests contain the largest reserves of sequestered carbon. Regional and national greenhouse gas reporting forums include forest carbon stocks because increases in forest carbon stocks represent quantifiable partial offsets to greenhouse gas emissions arising from the burning of fossil fuels. For example, carbon sequestration by U.S. forests represented an offset of more than 11 percent of total U.S. greenhouse gas emissions in 2013 (U.S. EPA 2015), and the continuing increase in Minnesota forest carbon stocks contributes to this effect. Total forest ecosystem carbon stocks in Minnesota are estimated to be 1,740 million tons of carbon, a 3 percent increase relative to 5 years ago.

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

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

What we found

Soil organic carbon accounts for approximately 74 percent of forest carbon stocks; live trees account for 17 percent, where 9 percent of that is in the wood and bark of the bole of trees with a d.b.h. of at least 5 inches (Fig. 48). Average aboveground carbon per acre increases with stand age, and greater net accumulation occurs in living trees and the understory (Fig. 49). Estimates for both pools decreased somewhat in the 101+ age class, but there was also considerably more variability among plots in those older stands relative to the younger age classes. Total carbon stocks are the product of per acre carbon and total acres of forest within each age class, and these are fairly well distributed over all the age classes (Fig. 49) with slightly more than half (54 percent) of the stocks in the older age classes. About 50 percent of total aboveground carbon stocks are represented by the middle two age classes, while the youngest age class accounts for less than 9 percent of forest carbon stocks.

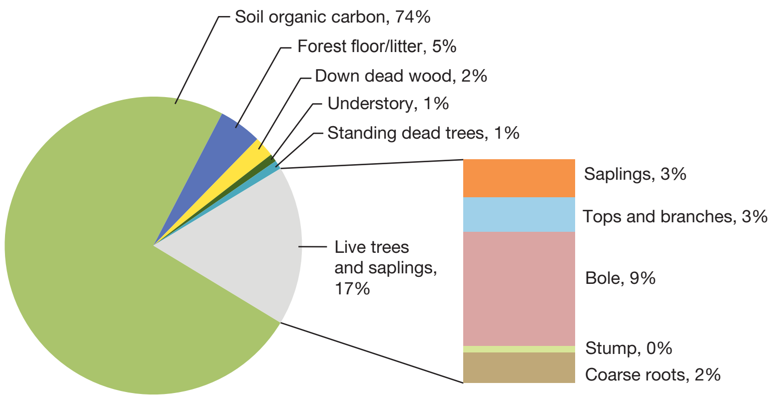


Figure 48.—Forest carbon stocks on forest land by carbon pool, Minnesota, 2013.

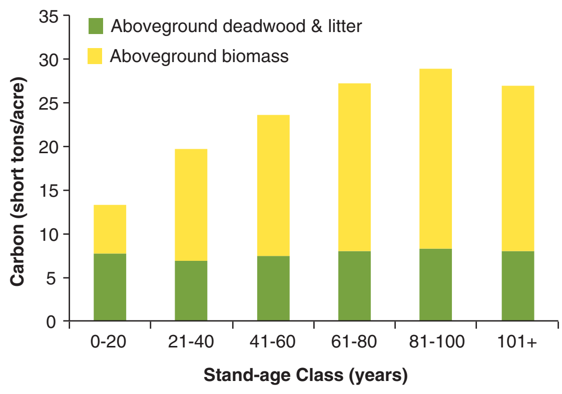


Figure 49.—Average carbon per acre by stand-age class and carbon pool, Minnesota, 2013.

Species composition can affect carbon stocks, resulting in variations in average carbon tons per acre for common forest-type groups identified within Minnesota forests (Fig. 50). Carbon per acre is classified into four categories: live (live tree and understory), dead (standing dead trees and down dead wood), litter, and soil, and variability among forest-type groups appears to be most closely associated with variations in the live category. Total carbon stocks are the product of per acre carbon and total acres, and in Minnesota the largest stocks are in aspen/birch where 578 million tons of carbon, or about 33 percent of all Minnesota forest carbon stocks, can be found. More than 90

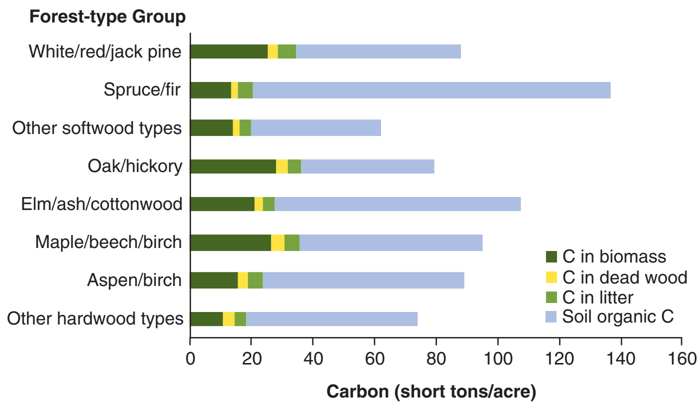


Figure 50.—Average carbon per acre by forest-type group and carbon pool, Minnesota, 2013.

percent of total carbon stocks are in the five most common forest-type groups: aspen/birch, spruce/fir, elm/ash/cottonwood, oak/hickory, and maple/beech/birch.

Actual carbon stocks for a particular stand depend on a combination of influences including site history, management, stand age, or component species, so individual sites can vary from the averages presented in Figures 48, 49, and 50. As an example, the state-wide average for tons of carbon per acre for live trees is 22 for stands that are identified as fully stocked, but the site-to-site variability is such that on 50 percent of measured plots, carbon stocks fell between 10 and 31 tons of carbon per acre with levels being greater than this amount in 25 percent of the plots and less than this amount in the remaining 25 percent.

The current carbon estimation methods and data were also applied to the 2008 Minnesota forest inventory (data not shown) to produce summaries consistent with those provided here for the 2013 inventory. Overall forest carbon per acre increased by 0.7 percent relative to 5 years ago, and live tree carbon values increased by 3.4 percent. In addition, total forest area increased over the same period so that total carbon stocks in 2013 are 3.0 percent greater than the equivalent values calculated for 2008.

What this means

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

Soils

Background

Rich soils are the foundation of productive forest land. Inventory and assessment of the forest soil resource provides critical baseline information on forest health and productivity, especially in the face of continued natural and human disturbance. The forest soils of Minnesota were sampled on 326 plots from 2000 through 2005. Soils change very slowly, and a remeasurement of the soil was delayed until 2012. Additionally, soils data require laboratory analyses to provide the complete suite of information (e.g., soil carbon content and nutrient concentrations). Unfortunately, these data are not available for analysis in this report. However, several analyses completed at the regional level are relevant to discussions of land use and forestry interactions with soil resources.

What we found

Peatland soils are relatively common in the northern parts of Minnesota (Fig. 51). Minnesota has more peatland area (over 6 million acres) than any other state in the U.S. except Alaska (Minnesota Department of Natural Resources 2015b). Their per-unit-area carbon stocks are exceptionally high; they cover 3 percent of the world's surface

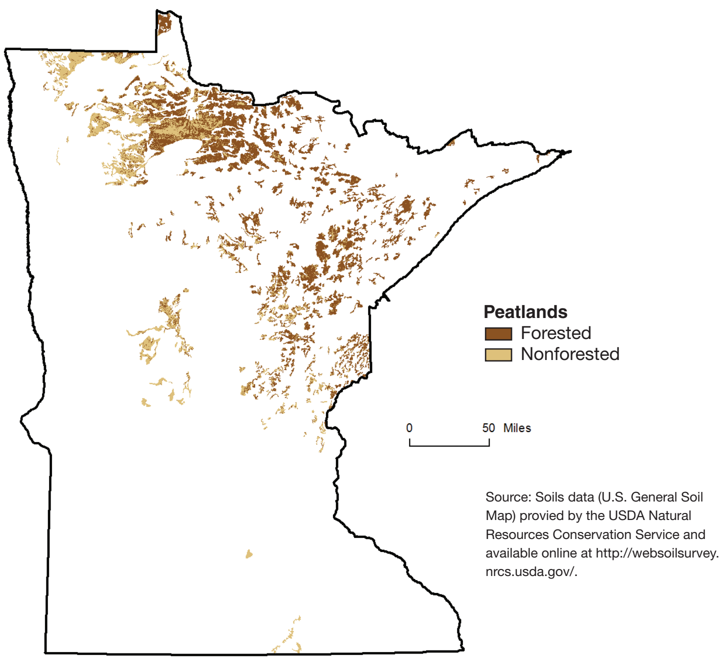


Figure 51.—Distribution of forested and nonforested peatlands in Minnesota, 2013.

area, but they store 30 percent of the globe's soil carbon. Peatland soils are also sensitive to climate change, and warming temperatures are expected to increase decomposition rates and release large amounts of stored carbon into the atmosphere. The Forest Service examined several methods of estimating peatland carbon and found that peat thickness is the best predictor of total carbon storage (Chimner et al. 2014).

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

Finally, several million dollars are being invested to facilitate Great Lakes restoration under the coordination by the U.S. Environmental Protection Agency. To prioritize investments, the Forest Service conducted a thorough analysis to identify which watersheds were the greatest contributors of sediment and phosphorus runoff into Lake Superior. Land use characteristics, such as forest cover, forest harvest, agriculture, and watershed storage (the abundance of lakes and wetlands), were useful predictors of stream water quality at river mouths. Figure 52 depicts predicted nephelometric turbidity unit (NTU) levels for watershed basins along the western shores of Lake Superior and Figure 53 depicts phosphorous delivery.

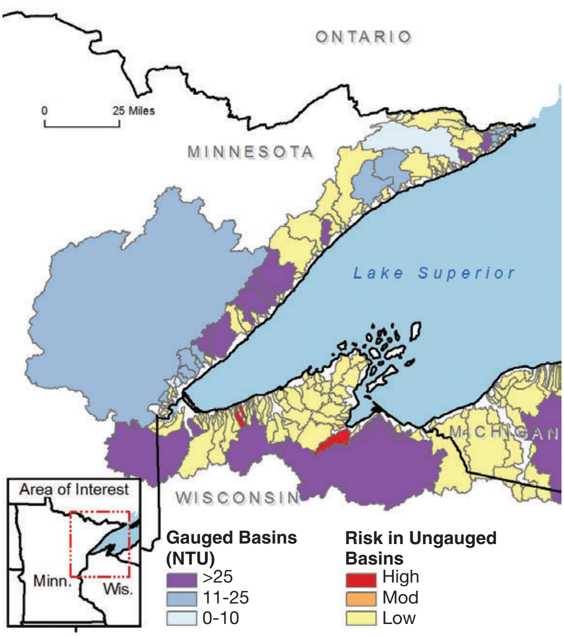


Figure 52.—Predictions of sediment delivery from gauged and ungauged watersheds draining into western Lake Superior. Adapted from Seilheimer et al. (2013).

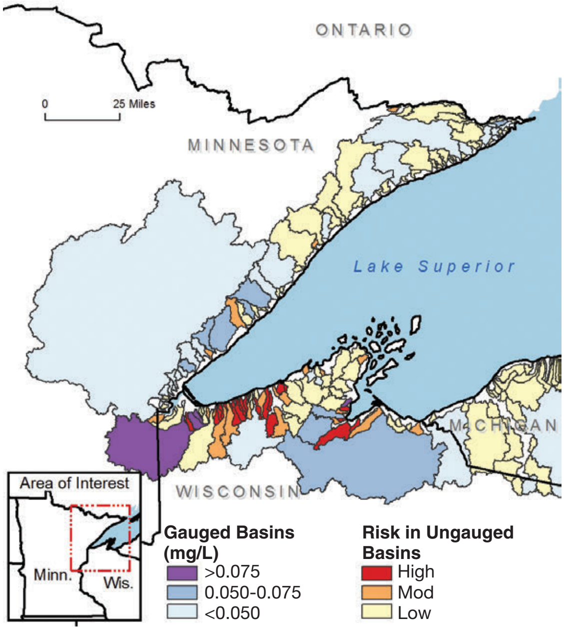


Figure 53.—Predictions of phosphorus delivery from gauged and ungauged watersheds draining into western Lake Superior. Adapted from Seilheimer et al. (2013).

What this means

The Forest Service and its partners are evaluating changes to soil inventory protocols which should provide greater precision in estimates of peatland soil carbon. Studies like the SPRUCE project in northern Minnesota (http://mnspruce.ornl.gov/), when integrated with improved inventories of peatlands, will improve our understanding and management of these important soil carbon stocks.

Sugar maple is found in Minnesota, but rates of increased mortality linked to atmospheric deposition are more commonly found in the eastern part of its range. Minnesota's location in the mid-continent generally isolates it from wind patterns that concentrate and deposit commercial and residential emissions of nitrogen and sulfur.

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

Land-use Change

Background

Although the total area of forest land in Minnesota has remained relatively stable between 2008 and 2013, some areas of the State have experienced forest loss, while other areas have seen increases in forest land. To better understand forest land dynamics in Minnesota, it is important to explore the underlying land-use changes occurring in the State.

FIA characterizes land area using several land use categories which can be generalized to these classes: forest, rangeland, agriculture (including pasture and cropland), developed land, water, and other (which, in Minnesota, is primarily composed of wetlands, including marshes and bogs). The conversion of forest land to other uses is referred to as gross forest loss, and the conversion of nonforest land to forest is known as gross forest gain. The magnitude of the difference between gross loss and gain is defined as net forest change. By comparing land use on current inventory plots with land use recorded for the same plots during the previous inventory, we can characterize forest land-use change dynamics. Understanding land-use change dynamics is essential for monitoring the sustainability of Minnesota forest resources and helps land managers make informed policy decisions.

What we found

Agricultural land is the dominant land use in Minnesota, covering 47 percent of the State's area (Fig. 54). Other nonforest land uses in the State include marshes and bogs (9 percent), developed land including rights-of-way (6 percent), water (6 percent), and rangeland (<1 percent). Approximately 32 percent of the total area (land and water) of Minnesota was forested in 2013. Most of the FIA plots in Minnesota either remained forested or stayed in a nonforest use (31 percent and 67 percent, respectively), and only the remaining 2 percent of plots experienced either a forest loss or gain from 2008 to 2013 (Fig. 55).

According to FIA remeasurement data, Minnesota lost 295,000 acres (2 percent) of forest land from 2008 to 2013 which was more than offset by a gain of approximately 748,000 (4 percent) during the same time period (Fig. 56). Forty-nine percent of the forest gains come from marshes and bogs. The remaining fifty-one percent of gains in forest comes from agricultural uses including cropland (14 percent), pasture (6 percent) and other agricultural land (6 percent), developed land (13 percent), water (6 percent), rights-of-way (5 percent), and rangeland (1 percent). Forty-five percent of the forest losses were diverted to marshes and bogs. The other fifty-five percent of forest loss went to development (17 percent), rights-of-way (11 percent), pasture (9 percent), cropland (7 percent), other agricultural land (5 percent), and water (6 percent) (Fig. 57).

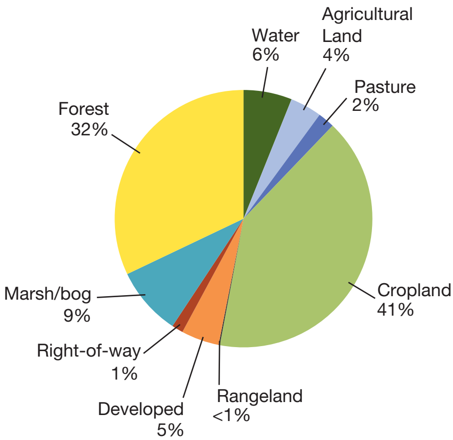


Figure 54.—Land use composition of remeasured plots, Minnesota, 2013.

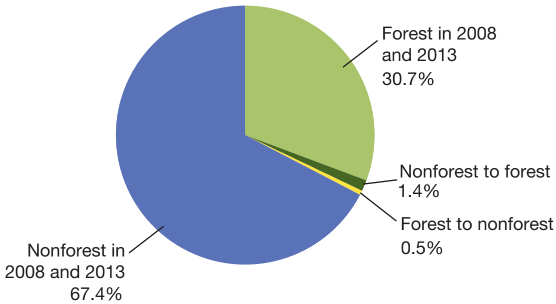


Figure 55.—Land-use change, Minnesota, 2009 to 2013.

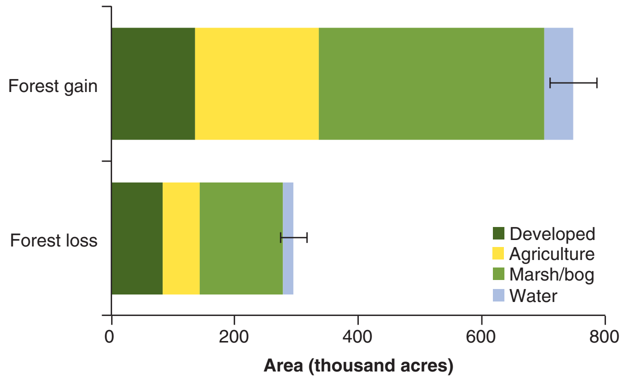
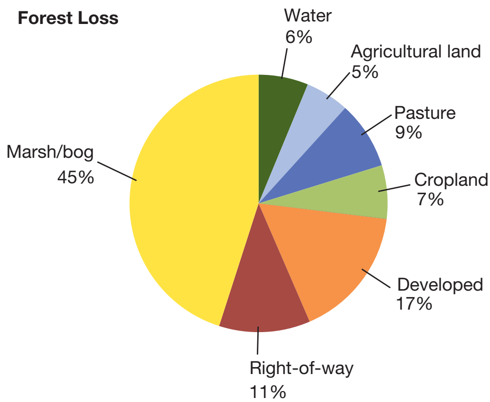


Figure 56.—Gross percent forest loss and forest gain by land use category, Minnesota, 2009 to 2013. Error bars represent a 68 percent confidence interval around the estimated mean.



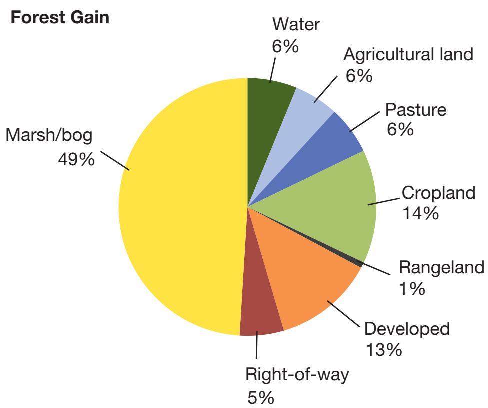


Figure 57.—Forest loss by current land use and forest gain by previous land use, Minnesota, 2009 to 2013.

FIA data can be used to characterize the forest land that has been lost and gained to see if it differs from the average characteristics of all forest land throughout Minnesota. The forests of Minnesota are dominated by stands in the large and medium diameter size classes with only 21 percent of forests in small diameter stands. However, the forest land that has been lost has a greater proportion of small diameter stands (43 percent) than in Minnesota as a whole.

Figure 58 shows the distribution of remeasured plots across Minnesota highlighting plots where forest land has been lost and gained. Forest change plots are concentrated in the northeastern region of Minnesota where forest cover is most prevalent. In the southern and western nonforest portion of the state, forest gains appear to be outpacing forest losses.

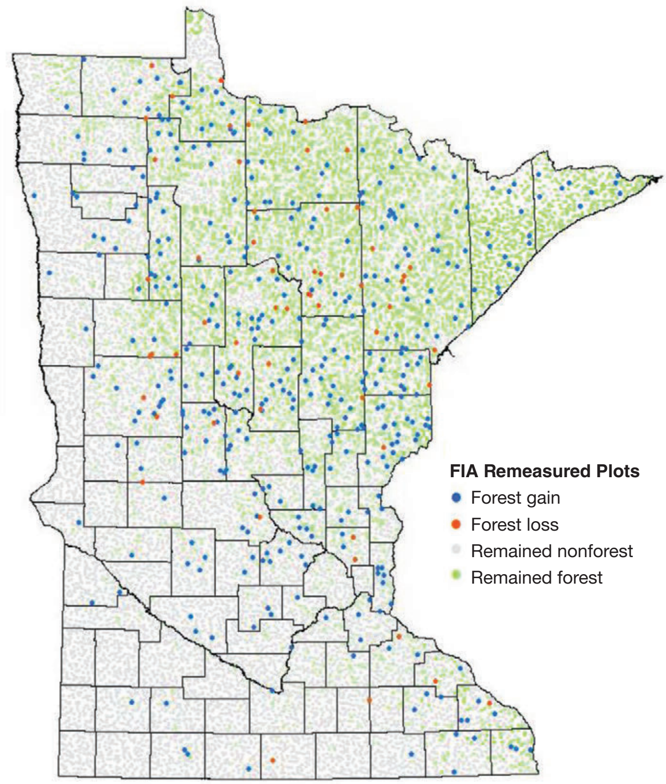


Figure 58.—Distribution of remeasurement inventory plots showing forest gains and losses, Minnesota, 2008 to 2013. Plot locations are approximate.

What this means

Overall, there was a modest (2 percent) net gain in forest land in Minnesota from 2008 to 2013 which suggests a continued conservation and valuation of the State's forest resources. This trend of increasing forest land is consistent with what was reported in the last inventory cycle (Miles et al. 2011), however the magnitude of the net gain was greater in the previous inventory. This difference in magnitude can be attributed primarily to a drop in the amount of nonforest land that reverted to forest. The amount of gross forest loss remained relatively stable between the two inventory cycles.

Nearly half of the forest losses and gains are going to and coming from wetland areas, primarily marshes and bogs. These are likely low-lying areas that are moving between forest and nonforest classifications due to weather (drought/flooding) or other natural causes such as beaver dams. These conditions are often not permanent and fluctuations of this type were also reported in the last inventory cycle.

Some of the gains and losses of forest land in Minnesota may be from marginal forest land moving into and out of the forest land base. This movement between forest and nonforest classifications may be a result of land meeting or not meeting FIA's definition of forest land due to small changes in understory disturbance, forest extent, or forest cover. These changes are also generally not permanent and may be more prevalent in forests with smaller sized stands. The fact that much of the forest change in Minnesota is occurring in smaller sized stands may support the idea that this type of nonpermanent land-use change is occurring in the State.

Some forest losses, including forest conversion to developed land, are likely permanent changes. The area of forest land lost to development, however, is relatively small in Minnesota. The primary land source for new development in the State is agriculture. Eighty percent of the gains in developed land come from converted agricultural land, versus 12 percent from forest land.

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

Forest Wildlife Habitat

Background

Forests, woodlands, and savannas provide habitats for many species of Minnesota birds (159 species), mammals (57 species), and amphibians and reptiles (31 species) (NatureServe, n.d.). Different forest types at different structural stages provide natural communities (habitats) at a coarse filter scale of conservation. Rare, imperiled, or wide-ranging wildlife species (i.e., species that make long distance movements) may not be fully served at this scale, so a "fine filter" approach is used to identify species-specific conservation needs. Representing an intermediate or meso-filter scale of conservation are specific habitat features (e.g., snags, riparian forest strips) which may serve particular habitat requirements for multiple species. This report characterizes habitats at the coarse-filter scale (forest age/size) and meso-filter scale (standing dead trees). For a description of coarse-, meso-, and fine-filter conservation scales see Hunter (2005).

Like all states, Minnesota has developed a State wildlife action plan (SWAP). The plan, "Tomorrow's Habitat for the Wild and Rare–An Action Plan for Minnesota Wildlife" (Minnesota Department of Natural Resources 2005), identifies 292 animal species of greatest conservation need (SGCN) and their focal habitats. Forest habitat-associated mammal, bird, reptile, amphibian, and insect SGCN occur in shrub/woodland-upland habitats such as oak savanna, jack pine woodland, and brush prairie (58 species); upland conifer (53 species); upland deciduous hardwood (45 species); lowland conifer (33 species); lowland deciduous (33 species); and upland deciduous aspen (31 species). Note that many of these SGCN are listed for more than one habitat type. The condition and trends in forest attributes of forest age and size are reported here. One of the fine-scale conservation issues associated with forest habitats is the presence and abundance of snags and nest cavities, so the quantity and distribution of standing dead trees is reported.

Wildlife habitat at a coarse-filter scale: stand age and stand size

Some species of wildlife depend upon early successional forests which typically have younger and/or smaller trees, while other species require older, interior forests containing large trees with complex canopy structure. Still other species inhabit the ecotone (edge) between different forest stages, and many require multiple structural stages of forests to meet different phases of their life history needs. Abundance and trends in structural and successional stages serve as indicators of population carrying capacity for wildlife species (Hunter et al. 2001). Historical trends in Minnesota forest habitats are reported for timberland, which makes up about 90 percent of all forest land in the state. For current habitat conditions, estimates are reported for all forest land. Aspen, which is the most abundant forest habitat in Minnesota, provides examples of SGCN in both young and old forest. American woodcock favors young aspen and paper birch stands with openings, especially on moist soils; boreal owls require much older aspens and may be limited by availability of nest cavities in large old aspen trees.

Wildlife habitat at a meso-filter scale: standing dead trees

Specific habitat features like nesting cavities and standing dead trees provide critical habitat components for many forest-associated wildlife species. Standing dead trees that are large enough to meet habitat requirements for wildlife are referred to as "snags." According to one definition, "for wildlife habitat purposes, a snag is sometimes regarded as being at least 10 inches (25.4 cm) in diameter at breast height and at least 6 feet (1.8 m) tall" (Society of American Foresters, n.d.). Standing dead trees serve as important indicators not only of wildlife habitat, but also for past mortality events and carbon storage. And, they serve as sources of down woody material (discussed elsewhere in this report), which also provides habitat features for wildlife. The number and density of standing dead trees, together with decay classes, species, and sizes, define an important wildlife habitat feature across Minnesota forests.

What we found

Stand age and stand size

The area of timberland in the small diameter stand-size class has increased steadily in Minnesota during the past several decades, nearly doubling since 1977. Timberland area in the large diameter stand-size class increased more gradually between 1977 and 1990, and area in the medium diameter stand-size class decreased between 1977 and 1990, but has remained stable during recent decades (Fig. 59). Between 1977 and 1990, area of timberland under 20 year years of age increased slightly. While timberland older than 100 years represents the smallest area of any age class, it has seen the largest relative change, nearly tripling in abundance between 1977 and 2013 (Fig. 60). Similarly, timberland of 81-100 years has more than doubled during that same period. In Minnesota, all three stand-size classes contain forests from at least five age classes. Medium diameter stand-size class is predominated by forests of 21-80 years of age, with lower abundance of both young (0-20 years) and old (>80 years) forest. Large diameter stand-size class has an age distribution skewed slightly to the right, predominated by age classes from 41-100 year. Not surprisingly, young forest (0-20 years) is the largest age class in the small diameter stand-size class, with decreasing area in each successively older age class (Fig. 61).

Figure 59.—Area of timberland by inventory year and stand-size class, Minnesota.

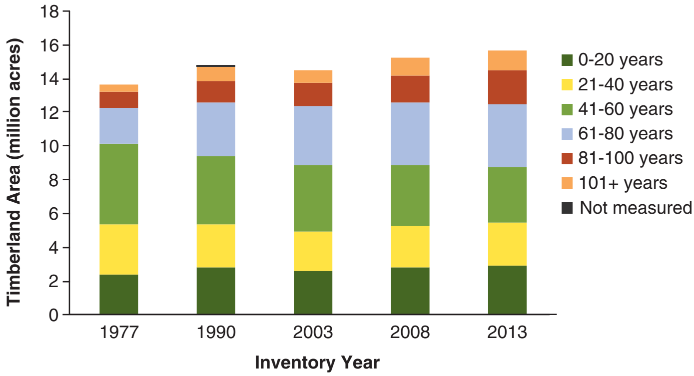


Figure 60.—Area of timberland by inventory year and stand-age class, Minnesota.

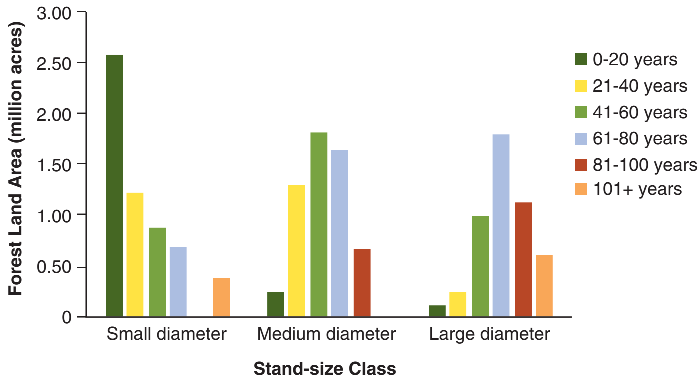


Figure 61.—Area of forest land by stand-size class and stand-age class, Minnesota, 2013.

Standing dead trees

FIA collects data on standing dead trees (at least 5 inches d.b.h.) of numerous species and sizes in varying stages of decay. According to current inventory data (2009-2013), more than 330 million standing dead trees are present on Minnesota forest land. This equates to an overall density of 19.0 standing dead trees per acre of forest land, with slightly higher densities on public (20.5) than on private (17.2) ownership. Five species groups each contributed more than 10 million standing dead trees, with the top groups of cottonwood and aspen contributing over 100 million trees (Fig. 62), of which 87 million are in quaking aspen alone. Relative to the total number of live trees in each species group, seven species groups exceeded 10 standing dead trees per 100 live trees (of at least 5 inches d.b.h.), with the jack pine species group topping the list at 30 standing dead trees per 100 live trees (of at least 5 inches d.b.h.) (Fig. 63). The great majority (82 percent) of standing dead trees were smaller than 11 inches d.b.h., with 41 percent between 5 and

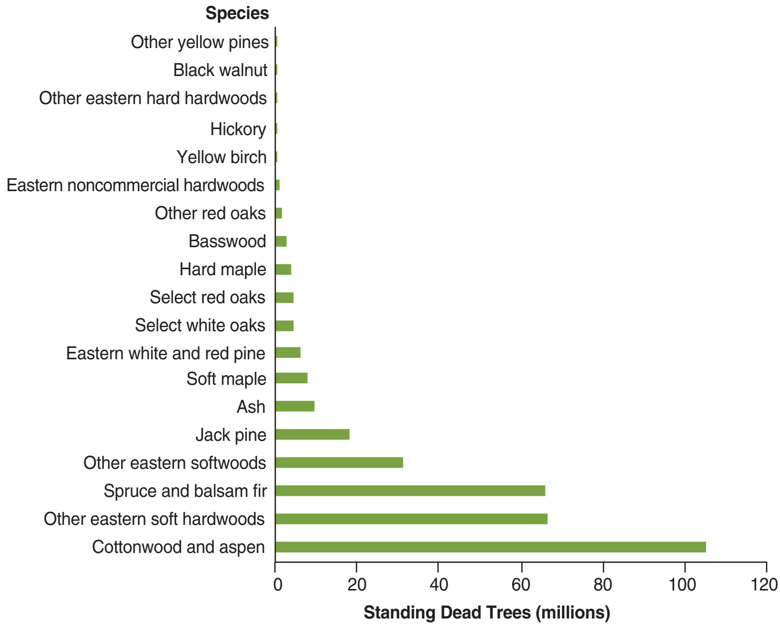


Figure 62.—Number of standing dead trees (for trees 5 inches d.b.h and larger) by species group, Minnesota, 2013.

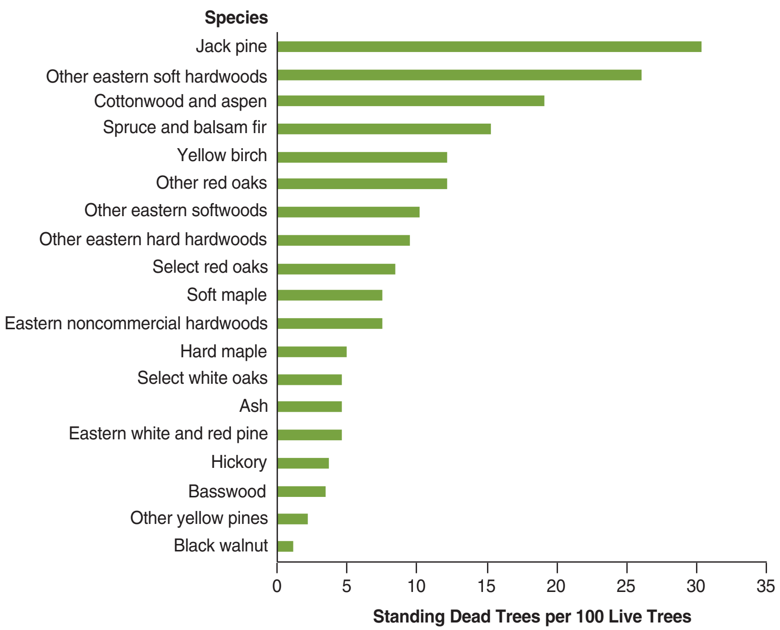


Figure 63.—Number of standing dead trees per 100 live trees (for trees 5 inches d.b.h. and larger) by species group, Minnesota, 2013.

6.9 inches d.b.h.; only 2 percent are over 17 inches (Fig. 64). Numbers of standing dead trees appear approximately normally distributed among decay classes for most diameter classes; the middle decay class (only limb stubs present) contained the most number of standing dead trees (32 percent).

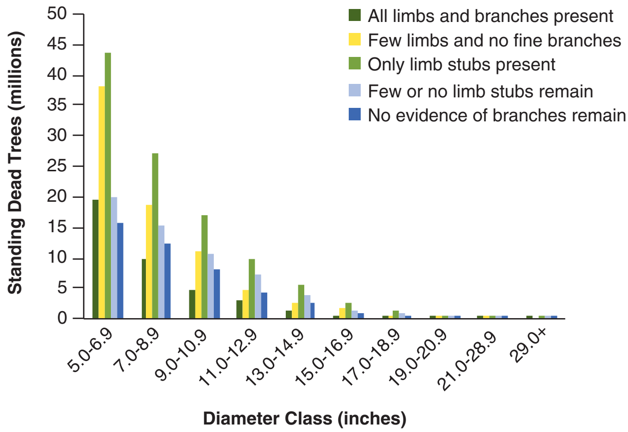


Figure 64.—Number of standing dead trees by diameter class and decay class, Minnesota, 2013.

What this means

Stand age and stand size

The area of timberland in large diameter stand-size class increased only modestly between 1977 and 2013, while timberland over 80 years is increasing at a more rapid rate. Area of timberland in small diameter stands increased markedly between 1977 and 2013, but during that period timberland area barely increased in the 0-20 year-old class. Both stand-size class and stand-age class are indicators of forest structural/successional stage. More than 87 percent of 0-20 year old forest is in small diameter size class, but only 45 percent of small diameter forest is 0-20 years of age. As expected, there is very little small diameter forest in the oldest stand-age classes and even less large diameter forest in the youngest stand-age class. The two age classes with the most size heterogeneity are 41-60 and 61-80 year classes. Such mixtures of different aged or sized trees provide a vertical diversity of vegetation structure that can enhance habitat conditions for some species. As illustrated by the aspen wildlife example above, there is a need to maintain 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. Managing forest composition and structure in a variety of conditions may conserve habitat and viable populations of many forest-associated wildlife species.

Standing dead trees

Snags and smaller standing dead trees result from a variety of potential causes, including diseases and insects, weather damage, fire, flooding, drought, and competition. The cottonwood and aspen species group contained the largest number of standing dead trees, but the jack pine species group had the highest density of standing dead trees per 100 live trees. About 19 standing dead trees are present for every acre of forest land; about 14 are present for every 100 live trees (of at least 5 inches d.b.h.). Dead trees may contain significantly more cavities per tree than occur in live trees (Fan et al. 2003), thereby providing habitat features for foraging, nesting, roosting, hunting perches, and cavity excavation for wildlife, from primary colonizers such as insects, bacteria, and fungi to birds, mammals, and reptiles. Most cavity nesting birds are insectivores which help to control insect populations. The availability of very large standing dead trees (snags) may be a limiting 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 Minnesota.

Urbanization and Fragmentation of Forest Lands

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). 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 (Charry 2007, Forman et al. 2003). Forest fragmentation can also affect forest ecosystem processes through changes in microclimate conditions, and it affects the ability of tree species to move in response to climate change (Iverson and Prasad 1998). Changes in the size of remaining forest patches, in their level of connectivity to other large patches, in the amount of general forest cover surrounding each patch, and in the amount of forest-nonforest edge all directly affect the amount and quality of interior forest and consequently the species and ecosystem functions that depend on these interior conditions. The same factors also affect the ease with which exotic, invasive, or generalist species can gain a foothold, the ability of wildlife and plant species to move across the landscape, and the ability of the forest to protect the quality and quantity of surface and ground water supplies.

Spatial landscape pattern metrics help quantify these different characteristics of fragmentation. In the last 5-year report (Miles et al. 2011), the amount of forest in edge versus core situations was examined with respect to the most widely used thresholds for interpreting likely impact. The results highlighted the considerable range of conditions between Minnesota's heavily forested northeast and the prairie southwest.

Metric values are sensitive to the resolution of the land cover data source used (Moody and Woodcock 1995), similar to the way that animal species see the landscape very differently depending on the scale at which they operate (e.g., the same patch that supplies interior forest conditions for one species is viewed as an unsuitable fragment by another species with higher quality or larger area requirements). Since important forest ecosystem processes operate at different scales, in this report current levels of fragmentation are examined at two scales. A spatial integrity index (SII) developed by Kapos et al.(2000) for the Global Forest Resources Assessment (FRA) was adapted 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 resulting metric for comparison where a value of 1 indicates an area that is highly fragmented while a value of 10 is used for an area of highest forest spatial integrity. Since even acceptably low misclassification rates in the source land cover data can be magnified into substantial errors in metric values (Langford et al. 2006, Shao and Wu 2008), spatial integrity was calculated at the two scales corresponding to two reliable and widely available source datasets, the 30 m (98.4 ft) scale of the 2011 National Land Cover Dataset (Jin et al. 2013), and the 250 m (820 ft) scale of the 2009 FIA forest cover dataset (Wilson et al. 2012). Both scales fall within the 10-1,000 km^2 scale at which pattern process linkages are often of greatest management interest (Forman and Godron 1986).

In the SII calculation, core forest is defined by patch size and local forest density within a defined local neighborhood area. An unconnected forest fragment is defined by its patch size, local forest density, and distance to a core forest area. The spatial integrity of all other forest lands are scaled between the core and unconnected fragment ends. At the 250 m scale, forest patch size must be greater than 1,544 acres (2.41 square miles) in order to be considered core forest, and forest land with a patch size of less than 30 acres (0.047 square miles) is considered an unconnected fragment. At the 30 m scale, forest patch size must be greater than 22 acres in order to be considered core forest, and forest land with a patch size of less than 2.5 acres is considered an unconnected fragment. The local forest density component is based on a circular area with a radius of 0.78 miles (1,223 acres) for the 250 m scale and on a circular area with a radius of 0.09 miles (16 acres) for the 30 m scale. Ninety percent of the respective neighborhoods must be classified as forest for a location to qualify as core forest (Table 12). These two 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 12.—Spatial integrity index (SII) parameters used in calculations at each scale

	Scale	
Definition of core	**250 m (820 ft)**	**30 m (98 ft)**
Patch size	>1,544 acres	>22 acres
Local forest density	90%	90%
Neighborhood radius	0.78 mile	0.09 mile
Definition of unconnected fragment	**250 m (820 ft)**	**30 m (98 ft)**
Patch size	<30 acres	<2.5 acres
Local forest density	10%	10%
Neighborhood radius	0.78 mile	0.09 miles
Distance to core	>4.2 miles	>0.5 miles

The population of Minnesota increased by 7.7 percent between 2000 and 2010, to 5.3 million people. During that same time period, the number of housing units increased by 14.4 percent (U.S. Census Bureau 2010). Stated another way, between 2000 and 2010, housing units increased at a pace 1.9 times the rate of increase in population, a trend not unique to Minnesota. 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 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 24 percent increase in the number of reported second homes from 2000 to 2010 could be a partial reflection of this trend in Minnesota (U.S. Census Bureau

2010). This can put additional pressure on forested areas even above the general increases in population density and housing density.

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

Roads are another important impact of urbanization that affect forest lands but are not completely captured by either of the previous two indices. In Minnesota as a whole, 25 percent of the forest land was within 650 feet of a road of some sort, and 44 percent was within 1,310 feet when calculated using NLCD 2006 forest (Fry et al. 2011) and U.S. Census Bureau (2000) roads (Fig. 65). Roads have a variety of effects: direct hydrological, chemical, and sediment effects; serving as vectors for invasive species; facilitating human access and use; increasing habitat fragmentation; and wildlife mortality. Actual impacts will vary depending on road width, use, construction, level of maintenance, and hydrologic and wildlife accommodations (e.g., Charry 2007, Forman et al. 2003); but in general, when greater than 60 percent of the total land area in 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

Considering SII classes at the 250 m scale, 61 percent of the forest land in Minnesota is core forest, 22 percent has high integrity, 7 percent has medium integrity, 1 percent has low spatial integrity, and 9 percent of the forest is in unconnected fragments. At the 30 m scale, with 22 acres or greater considered core forest, 62 percent of the forest land in Minnesota is core forest, 19 percent has high spatial integrity, 7 percent has medium or low integrity, and 13 percent of the forest is in unconnected fragments.

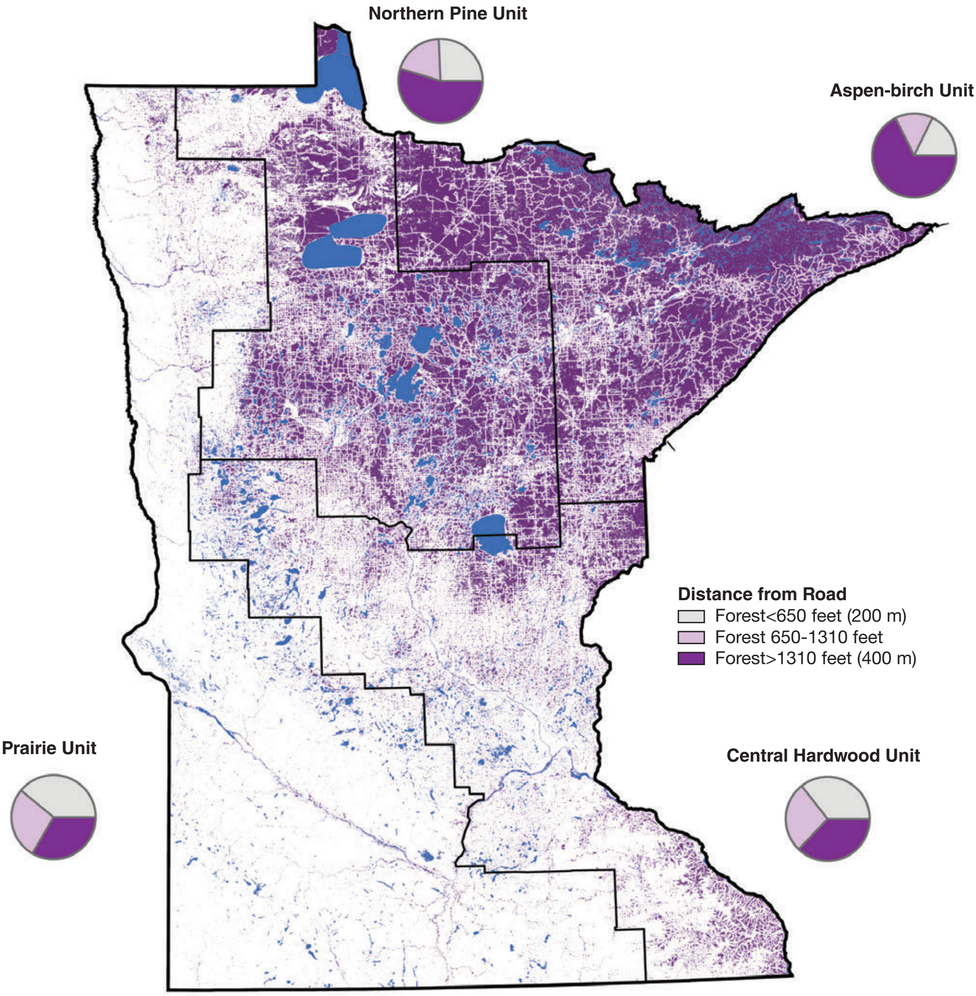


Figure 65.—Forest land by distance from the nearest road, Minnesota, 2006.

Table 13 contains a breakdown of SII values by FIA unit for both scales. Forest connectivity is highest in the Aspen-birch Unit and lowest in the Prairie Unit. The spatial distribution of forest land by SII classes at the 250 m scale is depicted in Fig. 66. Remaining large areas of relatively continuous forest clearly stand out. At the 30 m scale, the lower threshold of 22 acres for defining core forest means that more forest patches are considered core. Figure 67 compares the SII classes between the two scales for an area around Mille Lacs Lake. Note that the forest landscape data being used are depicting tree cover only and do not incorporate the presence of any development that might be associated with or underlying this tree cover.

Table 13.—Proportion of forest land by spatial integrity index (SII) class at 30 m and 250 m scales and FIA unit, Minnesota, 2013

Unit	Forest by 30 m spatial integrity class: Forest fragment	Low SII	Medium SII	High SII	Core forest	Forest by 250 m spatial integrity class: Forest fragment	Low SII	Medium SII	High SII	Core forest
	Percent					Percent				
Aspen-birch	1	0	3	17	78	0	0	1	14	84
Northern pine	7	1	7	21	64	7	2	10	32	49
Central hardwood	37	1	9	2	33	39	2	17	25	17
Prairie	74	1	6	10	8	92	1	5	2	0
Minnesota	13	1	6	19	65	9	1	7	22	61
MN after incorporating WUI areas	13	1	6	21	59	9	1	7	24	59

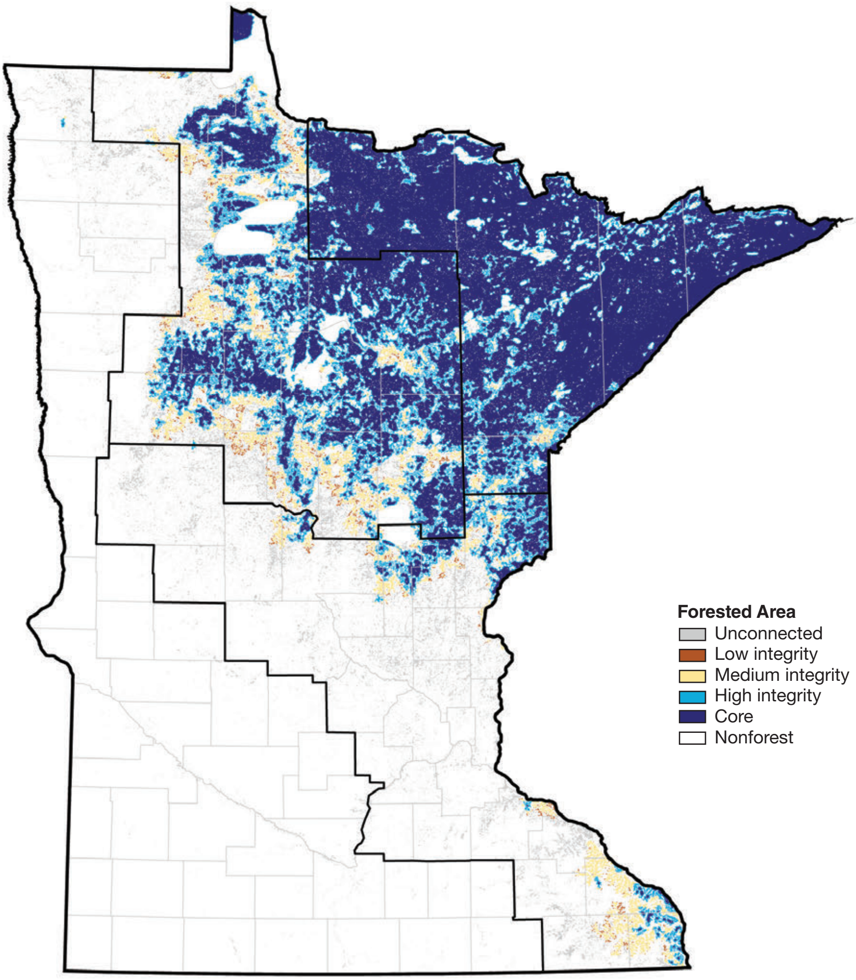


Figure 66.—Forest land by Spatial Integrity Index (SII) at the 250 m scale, Minnesota, 2006.

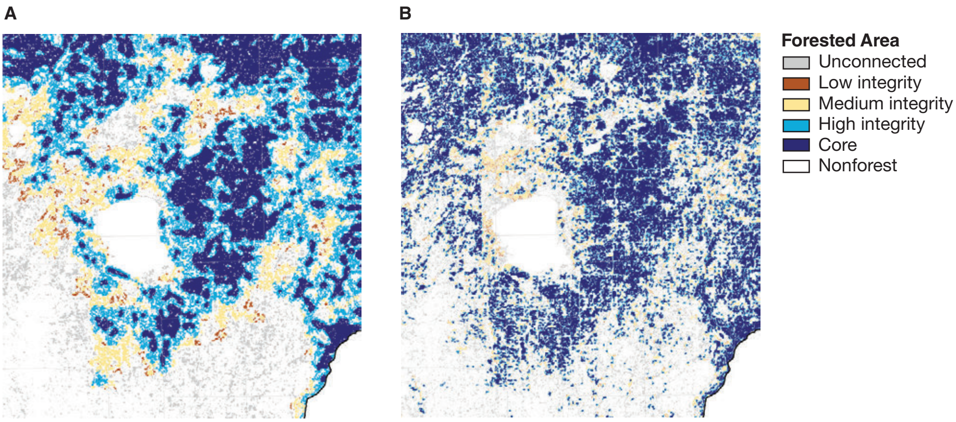


Figure 67.—Forest land by Spatial Integrity Index (SII) at the 250 m scale (A) and 30 m scale (B), in the region around Mille Lacs Lake, Minnesota, 2006.

Forest land with sufficient underlying housing density to qualify as WUI areas has been steadily increasing. In 1990, 7 percent of the forest land was in low and medium density WUI. In 2000 this increased to 8 percent of the forest land, and in 2010 it was 10 percent of the forest land in Minnesota. The distribution of forested WUI in Minnesota is depicted in Figure 68 and Table 14. Substantial impact to forest land is visible along the shores of Lake Superior, around Minneapolis/St. Paul, and around the lakes in the center of the State. These underlying house densities are poorly captured by the tree canopy cover data used in the calculation of spatial integrity above. When SII results at the 250 m scale are integrated with the WUI classes, 2 percent of Minnesota forest land moves from being core to lower spatial integrity classes, decreasing the proportion of forest land in the core class from 61 percent to 59 percent of forest land. At the 30 m scale, 3 percent of Minnesota forest land moves from being core to a lower spatial integrity class—from 62 percent to 59 percent. Although this is not a large number state-wide, the effects tend to concentrate in amenity-rich areas and the outskirts of major cities, and thus may be locally quite noticeable. Figure 69 depicts the changes in SII that occur when WUI status is incorporated, in the region between Mille Lacs and Leech lakes (Cass, Crow Wing, and Aiken counties).

Roads remain pervasive in the landscape, existing even in areas that appear to be continuous forest land from the air. In 2000, 18 percent of the forest area in the Aspen-Birch unit was within 650 feet of a road, and 26, 36, and 39 percent of the forest land in the Northern Pine, Central Hardwoods, and Prairie units, respectively, was within 650 feet of a road (U.S. Census Bureau 2000) (Table 14). Much of this area coincides with WUI areas of housing development. However, it is worth noting that the roads included in the U.S. Census Bureau data (TIGER[3] files) do not include

[3] TIGER (Topologically Integrated Geographic Encoding and Referencing) products are spatial extracts from the Census Bureau's MAF/TIGER database, containing features such as roads, railroads, rivers, as well as legal and statistical geographic areas.

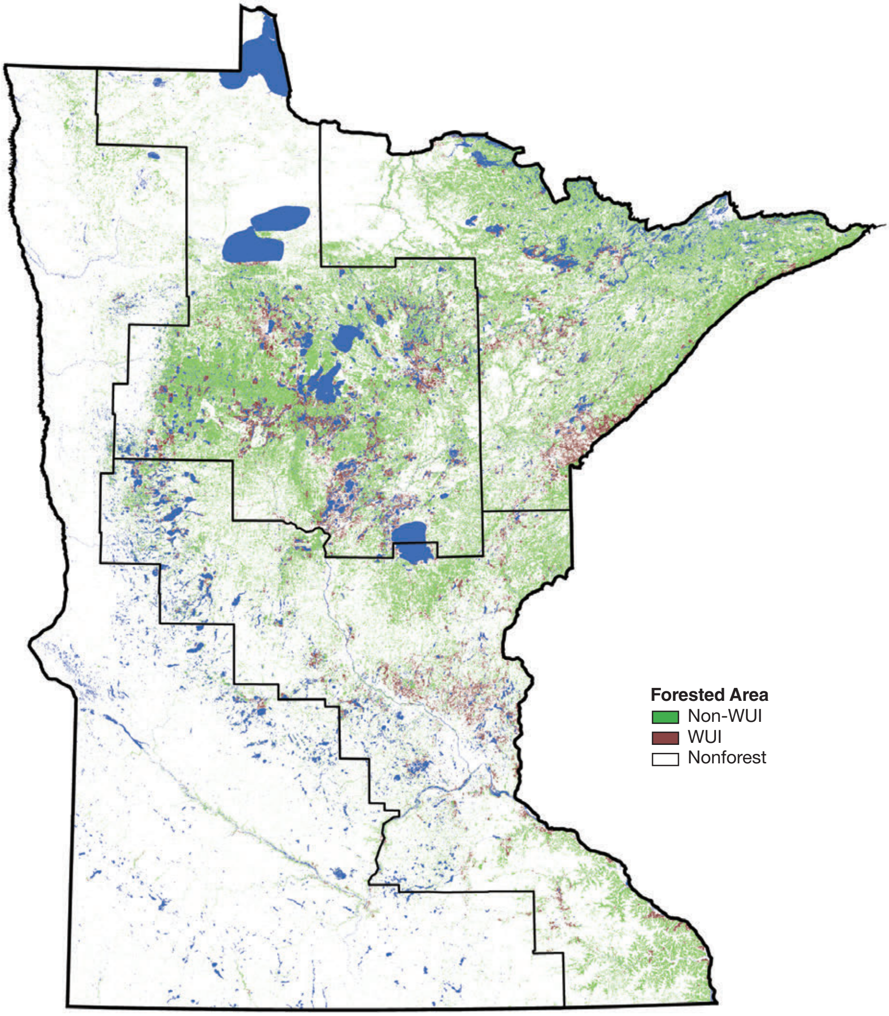


Figure 68.—Forest land by wildland urban interface (WUI status), Minnesota, 2006.

Table 14.—The distribution of forest land with respect to several urbanization and fragmentation factors, expressed as a percentage of the forest land in each FIA unit, Minnesota, 2013

Unit	Amount of total land in forest[a]	Forest land in WUI intermix[b]	Forest land <650 feet from a road[c]
	---------- *Percent* ----------		
Aspen-birch	82	7	18
Northern pine	60	12	26
Central hardwood	24	12	36
Prairie	4	3	39
State total	34	10	25

[a] Percent forest estimate based on NLCD 2011. Values are generally higher than estimates from FIA plot data.

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

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

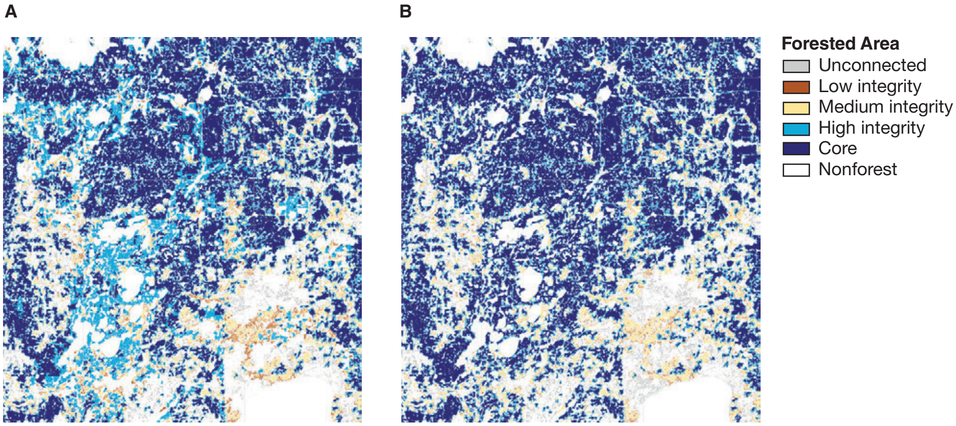


Figure 69.—Forest land by Spatial Integrity Index (SII) at the 30 m scale, with (A) and without (B) incorporating WUI status into SII, in the region between Mille Lacs and Leech lakes (Cass, Crow Wing, and Aiken counties), Minnesota, 2006.

many minor roads not associated with housing development, and that including these minor roads actually doubles road densities in areas like northern Wisconsin (Hawbaker and Radeloff 2004).

What this means

When looking at either the 250 m or the 30 m scales, only about 60 percent of the forest land in Minnesota meets the definition of core forest statewide, and approximately 9 to 13 percent of the forest land is in unconnected fragments or has low spatial integrity. Bringing WUI areas into the calculation does not affect the state-wide numbers substantially but has a considerable affect in several local areas. Bringing roads into the calculation, even at the levels available in the 2000 Census TIGER dataset, reduces the integrity of some areas still further.

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

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

2008, Kline et al. 2004, Wear et al. 1999). Continuing fragmentation, parcelization, and urbanization can be barriers to stewardship if they result in forest tracts that are too small or too isolated for effective management (Shifley and Moser 2016).

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

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

Socioeconomics

A red pine plantation that has been thinned twice, located in southern Carlton County, MN. Photo by Eli Sagor, used with permission (https://creativecommons.org/licenses/by-nc/2.0/legalcode).

Private Woodland Owner Survey

Background

How land is managed is primarily the owner's decision. Therefore, to a large extent, the availability and quality of forest resources are determined by landowners, including recreational opportunities, timber, and wildlife habitat. By understanding the priorities of forest land owners, leaders of the forest conservation community can better help meet the needs of each owner, and in so doing, help conserve the State's forests for future generations. The National Woodland Owner Survey (NWOS), conducted by the U.S. Forest Service Forest Inventory and Analysis program, studies attitudes, management objectives, and concerns of private forest landowners. It focuses on the diverse and dynamic group of owners that is the least understood—families, individuals, and other unincorporated groups, collectively referred to as "family forest owners." The NWOS data reported here are based on the responses from 351 family forest ownerships from Minnesota that participated between 2011 and 2013.

What we found

Public agencies control just over half (55 percent) of the forest land in Minnesota and private ownerships own the other 45 percent of the forest land in the State (Fig. 70). Of the private acres, an estimated 6.0 million acres are owned by family forest owners, an ownership group discussed in more detail below. Corporations, most of which are focused on the commercial production of timber, own 1.1 million acres, and the remaining private forest land (nearly 700,000 acres) is owned by conservation organizations, unincorporated clubs and partnerships, and Native American tribes. Public owners control 9.6 million acres of Minnesota forest land. State forest, park, and wildlife agencies are stewards of 4.1 million acres of forest land. Federal and local government agencies each control just under 3 million acres.

As was previously mentioned, family forest owners own 6.0 million acres of forest land in Minnesota. Most of these owners own 10 or more acres of land. According to the NWOS, there are an estimated 114,000 family forest ownerships across Minnesota that each own at least 10 acres of forest land, a collective 5.6 million acres. The average forest holding size of this group is 49 acres; 74 percent of these family forest ownerships own less than 50 acres of forest land, but 64 percent of the family forest land is in holdings of at least 50 acres (Fig. 71). The primary reasons for owning forest land are related to aesthetics, wildlife, nature protection, and privacy (Fig. 72). 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. 73). Most family forest ownerships have not participated in traditional forestry management and assistance programs in the past 5 years (Fig. 74); the most common form of assistance is having received management advice, but less than 20 percent of the ownerships received advice. Demographic information was collected for the self-proclaimed, primary decisionmaker for the forest land. The average age of family forest owners in Minnesota is 62 years with 44 percent of the family forest land owned by people who are at least 65 years of age (Fig. 75).

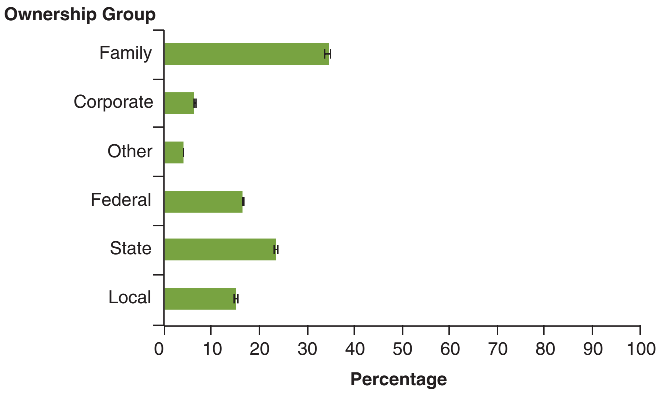


Figure 70.—Distribution of forest land by ownership group, Minnesota, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

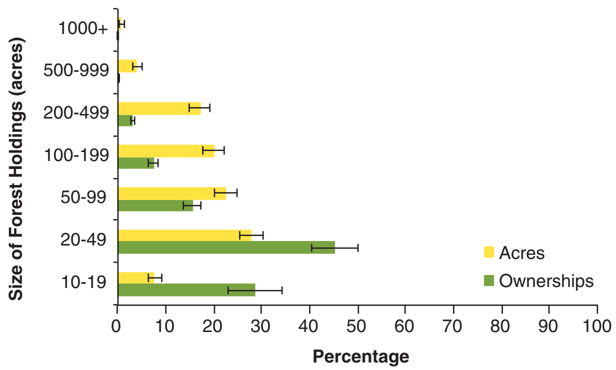


Figure 71.—Family forest ownerships (with 10+ acres) and acres of forest land by size of forest land holdings, Minnesota, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

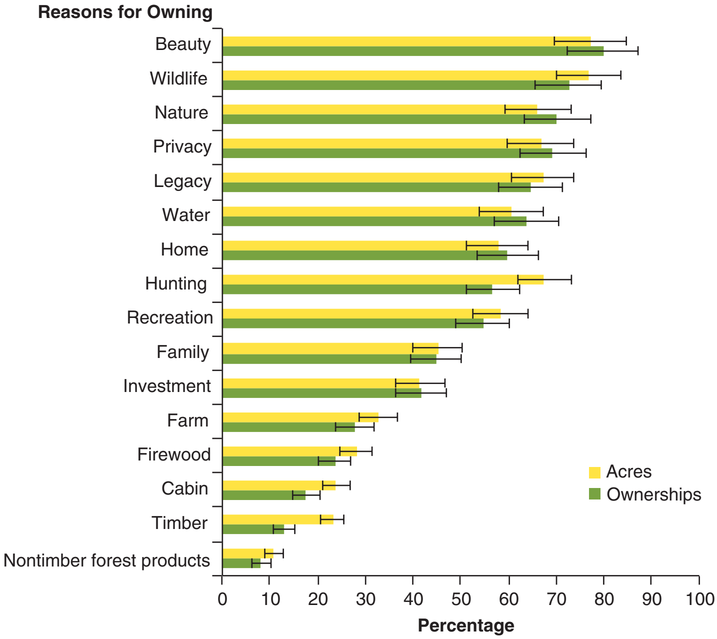


Figure 72.—Family forest ownerships (with 10+ acres) and acres of forest land by reasons for owning, Minnesota, 2013. Numbers include ownerships who ranked each objective as very important or important on a 5-point Likert scale. Error bars represent a 68 percent confidence interval around the estimated mean.

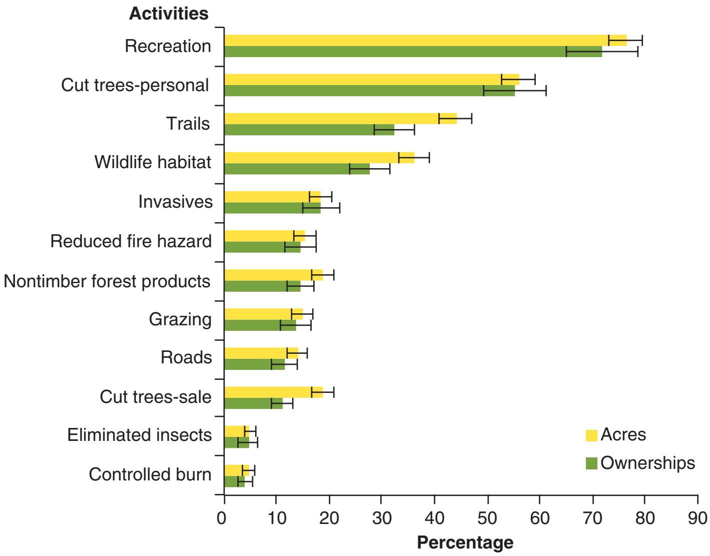


Figure 73.—Family forest ownerships (with 10+ acres) and acres of forest land by activities in the past 5 years, Minnesota, 2013. Categories are not exclusive. Error bars represent a 68 percent confidence interval around the estimated mean.

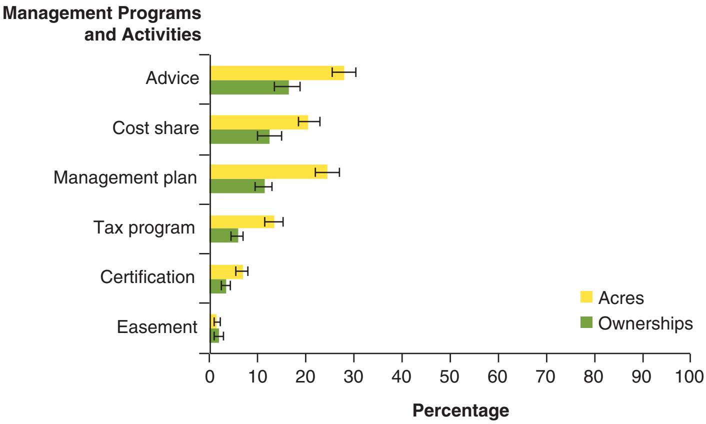


Figure 74.—Family forest ownerships (with 10+ acres) and acres of forest land by participation in forest management programs during the past 5 years, Minnesota, 2013. Categories are not exclusive. Error bars represent a 68 percent confidence interval around the estimated mean.

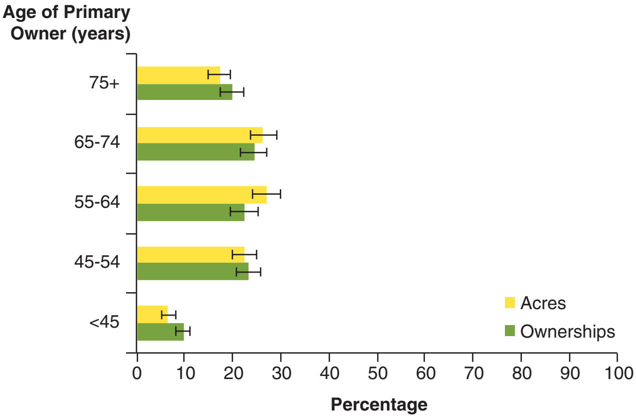


Figure 75.—Family forest ownerships (with 10+ acres) and acres of forest land by age of primary owner, Minnesota, 2013. Error bars represent a 68 percent confidence interval around the estimated mean.

What this means

The fate of the forests lies primarily in the hands of those who own and control the land. It is therefore critical to understand forest owners and what policies and programs can help them conserve the forests for current and future generations. Looking particularly at family forest ownerships, the group that is the least understood and the fate whose land is arguably the most uncertain, they own their land primarily for amenity reasons, but many are actively doing things with their land. That being said, an estimated 90 percent of them do not report having a management plan nor have they participated in most 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 those run through the University of Minnesota Extension program (http://z.umn.edu/legacyplanning), 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 Products Output

Background

In Minnesota, forest products manufacturing and related sectors directly contribute $9.7 billion industry output and $3 billion value to the Minnesota economy, employing about 40,370 people with a $1.8 billion payroll (Deckard and Skurla 2011). Timber harvesting and processing produces a stream of economic benefits shared by timber owners, managers, marketers, loggers, truckers, and processors. Knowledge about this important industry helps decisionmakers better manage the State's forests to insure a steady supply of the necessary raw material. Surveys of Minnesota's primary wood-using industry, its use of roundwood, and its generation and disposition of mill residues remaining after processing are conducted periodically, with the most recent survey being completed in 2010. This information is supplemented with the most recent surveys conducted in surrounding states that processed wood from Minnesota.

What we found

There were 417 active primary wood-processing mills in Minnesota in 2010. The largest processors of roundwood in Minnesota are pulp mills, of which there are 5 in the State, sawmills (362 mills), and particleboard mills (4 mills). These three mill types processed nearly 95 percent of the total receipts of 239 million cubic feet at Minnesota mills (Fig. 76).

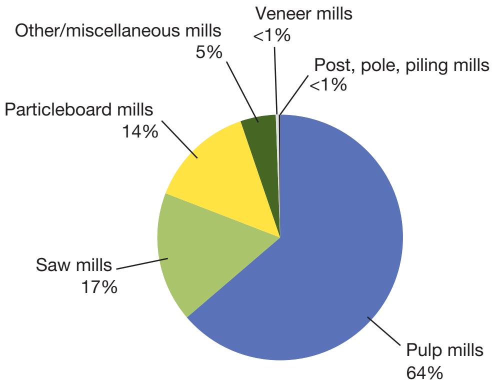


Figure 76.—Industrial roundwood receipts at primary wood-using mills by type of mill, Minnesota, 2010.

A total of 226.1 million cubic feet of industrial roundwood was harvested from Minnesota forest lands in 2010. Pulpwood accounted for the overwhelming majority of the total harvest (Fig. 77). The aspen species group was by far the most harvested species group, with most of that volume going to pulp mills and particleboard mills. Other species groups that made up a considerable portion of the total harvest were spruce, red pine, jack pine, balsam fir, and white birch (Fig. 78). The harvesting of industrial roundwood created 110.6 million cubic feet of harvest residues that were left on the ground. Nearly 87 percent of harvest residues came from nongrowing stock sources, such as tops and limbs, crooked or rotten trees, or dead trees.

The processing of industrial roundwood into products in Minnesota primary wood-using mills generated 1.5 million green tons of wood and bark residues. Nearly 69 percent of mill residues were used as industrial fuel. Thirteen percent were used as mulch and 7 percent were used as animal bedding. Only one-half of one percent of mill residues went unused (Fig. 79).

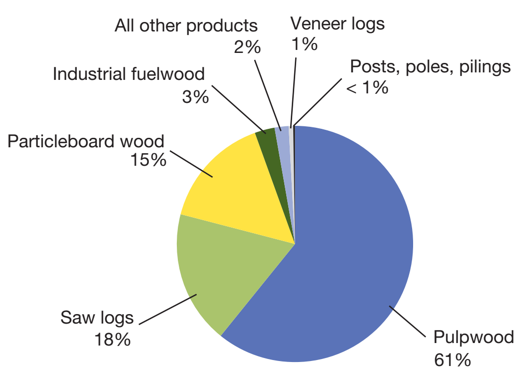


Figure 77.—Industrial roundwood production by type of product, Minnesota, 2010.

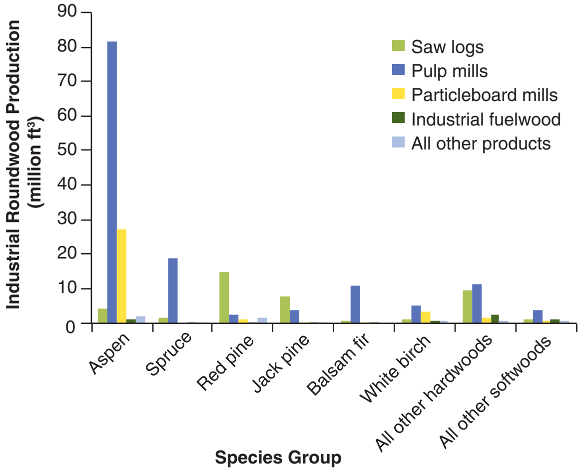


Figure 78.—Industrial roundwood production by species group and type of product, Minnesota, 2010.

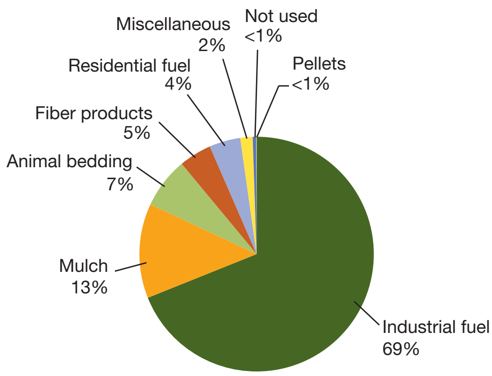


Figure 79.—Disposition of mill residues, Minnesota, 2010.

What this means

The timber products industry plays a vital role in the economy of rural Minnesota. This is especially true in the heavily forested northeastern portion of the State, where 90 percent of industrial roundwood volume harvested in Minnesota originates. The numerous mills in that area provide woodland owners with an outlet to sell timber and provide jobs to local citizens. Based on current growing-stock volume on timberland statewide, the 2010 harvesting of industrial roundwood represents just 2 percent of that total. This rate of harvest will ensure plenty of raw materials to sustain the forest products industry into the future.

Future Forests of Minnesota

Background

This section focuses on anticipated changes to the forests of Minnesota between 2010 and 2060. The analysis is derived entirely 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 280 thousand 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 include:

1) A1B—Rapid economic globalization. International mobility of people, ideas, and technology. Strong commitment to market-based solutions. Strong commitment to education. High rates of investment and innovation in education, technology, and institutions at the national and international levels. A balanced energy portfolio including fossil intensive and renewable energy sources. Utilizes the CGCM3.1 climate model (Canadian Centre for Climate Modelling and Analysis, n.d.b).
2) A2—Consolidation into economic regions. Self-reliance in terms of resources and less emphasis on economic, social, and cultural interactions between regions. Technology diffuses more slowly than in the other scenarios. International disparities in productivity, and hence income per capita, are largely maintained or increased in absolute terms. Utilizes the CGCM3.1 climate model.

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

The three storyline variations include:

1) C—Standard variation—available for all three storylines (A1B, A2, and B2).

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 the emerald ash borer (EAB) with associated mortality of all ash trees in the affected areas—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 recent trend of increasing forest area in Minnesota (Fig. 80). Specifically, over the next 50 years forest land area is projected to decline from an estimated 17.0 million acres in 2010 to 16.4 million acres (-4 percent) in 2060 under scenario A1B-C; to 16.5 million acres (-3 percent) under scenario A2-C; and to 16.6 million acres (-2 percent) under scenario B2-C. The anticipated losses of forest land are still relatively small compared to the cumulative decrease in forest area since the initial inventory of Minnesota forests in the 1930s. Only three scenarios are represented in Figure 80 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.

Emerald ash borer was detected in Minnesota in May 2009. Under scenario A2-EAB there is a slight increase in the area of the elm/ash/cottonwood forest-type group but not nearly as large as the increase in elm/ash/cottonwood for scenarios A1B-C, A2-C, and B2-C (Fig. 81). The loss of the ash component is partially offset by increases in other associated species in the elm/ash/cottonwood forest-type group.

The impacts of EAB are more pronounced in Figure 82. Only the three high biomass utilization variation scenarios (A1B-BIO, B2-BIO, and A2-BIO) have lower levels of live tree volume in 2060 than does the A2-EAB scenario. The ash volume is

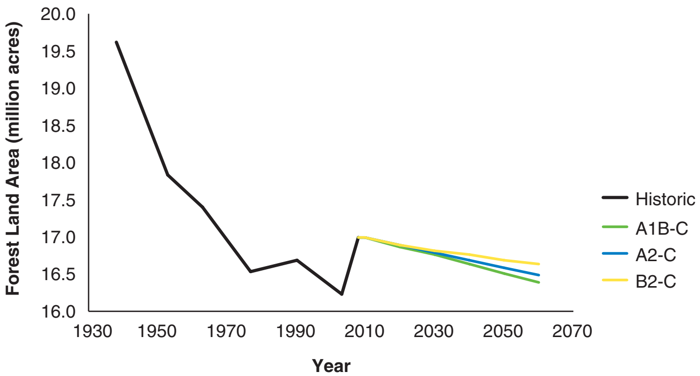


Figure 80.—Projected forest land area by scenario, Minnesota, 2010-2060.

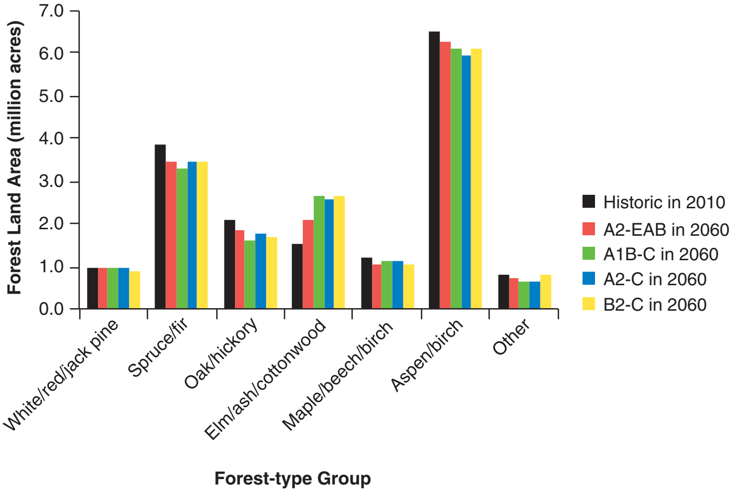


Figure 81.—Forest land area by forest-type group and scenario, Minnesota, 2010 and 2060.

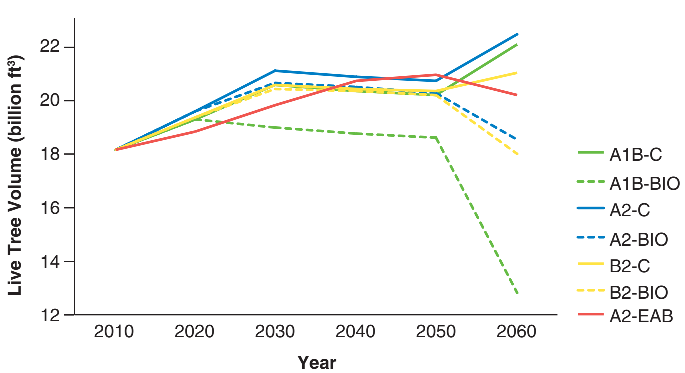


Figure 82.—Live tree volume on forest land by scenario, Minnesota, 2010-2060.

modeled to increase till 2030 and then fall to zero over the next two decades. Under the standard scenarios (A1B-C, A2-C, and B2-C), total live tree volume is expected to increase until approximately 2030 (despite losses in forest land area) and then decrease slightly for 20 years before increasing again in 2060. The area of forest land is expected to decrease, but the volume per acre is expected to increase as forests continue to mature.

What this means

The projected losses of forest land are relatively small compared to the cumulative decrease in forest area from the 1930s to 2003. In fact the increase in forest area from 2003 to 2010 is only expected to be partially offset by projected forest land area losses from 2010 to 2060.

Literature Cited

Abrams, M.D. 1992. **Fire and the development of oak forests.** Bioscience. 42(5): 346-353. http://dx.doi.org/10.2307/1311781.

Anderson, R.L.; G.W. Anderson; Schipper, A.L., Jr. 1979. **Hypoxylon canker of aspen.** Forest Insect and Disease Leaflet 6 (revised). Washington, DC: U.S. Department of Agriculture, Forest Service, Northeastern Area State & Private Forestry. 7 p.

Augustine, D.J.; deCalesta, D. 2003. **Defining deer overabundance and threats to forest communities: from individual plants to landscape structure.** Ecoscience. 10(4): 472-486.

Bailey, R.G. 1980. **Description of the ecoregions of the United States.** Misc. Pub. 1391. Washington, DC: U.S. Department of Agriculture, Forest Service. 77 p.

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

Belcher, D.M.; Holdaway, M.R.; Brand, G.J. 1982. **A description of STEMS: the stand and tree evaluation and modeling system.** Gen. Tech. Rep. NC-79. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 18 p.

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

Butler, B.J. 2008. **Family forest owners of the United States, 2006.** Gen. Tech. Rep. NRS-27. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 72 p. http://dx.doi.org/10.2737/NRS-GTR-27.

Canadian Centre for Climate Modelling and Analysis. [N.d.a.]. **CGCM2-coupled global climate model, medium resolution (T47).** Ottawa, ON, Canada: Environment Canada. http://www.cccma.ec.gc.ca/models/cgcm2.shtml (accessed July 27, 2012).

Canadian Centre for Climate Modelling and Analysis. [N.d.b.]. **CGCM3.1-coupled global climate model (CGCM3), medium resolution (T47).** Ottawa, ON, Canada: Environment Canada. http://www.cccma.ec.gc.ca/models/cgcm3.shtml (accessed July 27, 2012).

Charry, B. 2007. **Conserving wildlife on and around Maine's roads.** Augusta, ME: Beginning with Habitat, Maine Audubon, and Maine Department of Transportation. 10 p. http://www.beginningwithhabitat.org/pdf/MARoadsWildlifeFINAL.pdf (accessed March 23, 2015).

Chimner, R.A.; Ott, C.A.; Perry, C.H.; Kolka. R.K. 2014. **Developing and evaluating rapid field methods to estimate peat carbon.** Wetlands. 34: 1241-1246. http://dx.doi.org/10.1007/s13157-014-0574-6.

Conservation Biology Institute. 2012. **Protected areas database of the United States, PAD-US (CBI edition).** http://consbio.org/products/projects/pad-us-cbi-edition (accessed March 23, 2015).

Cunningham, R.N.; Horn, A.G.; Quinney, D.N. 1958. **Minnesota's Forest Resources, 1958.** Forest Resour. Rep. 13. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station. 53 p.

Deckard, D.L. 2014. **Minnesota 2013 public stumpage price review and price indices.** St. Paul, MN: Minnesota Department of Natural Resources, Division of Forestry. http://files.dnr.state.mn.us/forestry/timber_sales/stumpage/stumpageReviewReport2013.pdf (accessed March 27, 2015).

Deckard, D.L.; Skurla, J.L. 2011. **Economic contribution of Minnesota's forest products industry-2011 edition.** St. Paul, MN: Minnesota Department of Natural Resources, Division of Forestry. 18 p.

Donovan, T.M., Lamberson, R.H. 2001. **Area-sensitive distributions counteract negative effects of habitat fragmentation on breeding birds.** Ecology. 82(4): 1170-1179. http://dx.doi.org/10.2307/2679912.

Fan, Z.; Shifley, S.R.; Spetich, M.A.; Thompson, F.R., III.; Larsen, D.R. 2003. **Distribution of cavity trees in midwestern old-growth and second-growth forests.** Canadian Journal of Forest Research. 33: 1481-1494. http://dx.doi.org/10.1139/x03-068.

Food and Agricultural Organization of the United Nations [FAO]. 2010. **Global forest resources assessment 2010: main report.** FAO Forestry Paper 163. Rome, Italy: Food and Agricultural Organization. 340 p.

Forman, R.T.T.; Godron, M. 1986. **Landscape ecology.** New York, NY: J. Wiley & Sons. 619 p. ISBN: 9780471870371.

Forman, R.T.T.; Sperling, D.; Bissonette, J.A.; Clevenger, A.P.; Cutshall, C.D.; Dale, V.H.; Fahrig, L.; France, R.L.; Goldman, C.R.; Heanue, K.; Jones, J.; Swanson, F.; Turrentine, T.; Winter, T.C. 2003. **Road ecology: science and solutions.** Washington, DC: Island Press. 504 p. ISBN: 9781559639330.

Fry, J.; Xian, G.; Jin, S.; Dewitz, J.; Homer, C.; Yang, L.; Barnes, C.; Herold, N.; Wickham, J. 2011. **Completion of the 2006 national land cover database for the conterminous United States.** Photogrammetric Engineering and Remote Sensing. 77(9): 858-864.

Gilbart, M. 2012. **Under cover: wildlife of shrublands and young forest.** Cabot, VT: Wildlife Management Institute. 87 p.

Greenberg, C.H.; Collins, B.S.; Thompson, F.R., III. 2011. **Sustaining young forest communities: ecology and management of early successional habitat in the Central Hardwood region, USA.** Managing Forest Ecosystems, Volume 21. New York, NY: Springer. 310 p. http://dx.doi.org/10.1007 /978-94-007-1620-9.

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

Hammer, R.B.; Stewart, S.I.; Winkler, R.L.; Radeloff, V.C.; Voss, P.R. 2004. **Characterizing dynamic spatial and temporal residential density patterns from 1940-1990 across the north central United States.** Landscape and Urban Planning. 69: 183-199. http://dx.doi.org/10.1016/j.landurbplan.2003.08.011.

Hawbaker, T.J.; Radeloff, V.C. 2004. **Roads and landscape pattern in northern Wisconsin based on a comparison of four road data sources.** Conservation Biology. 18(5): 1233-1244. http://dx.doi.org/10.1111/j.1523-1739.2004.00231.x.

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

Hewes, J.H.; Butler, B.J.; Liknes, G.C.; Nelson, M.D.; Snyder, S.A. 2014. **Public and private forest ownership in the conterminous United States: distribution of six ownership types—geospatial dataset.** Fort Collins, CO: Forest Service Research Data Archive. http://dx.doi.org/10.2737/RDS-2014-0002.

Holt, H.A.; Fischer, B.C. 1979. **An overview of oak regeneration problems.** In: Holt, H.A.; Fischer, B.C., eds. Regenerating oaks in upland hardwood forests: proceedings of the 1979 John S. Wright forestry conference. West Lafayette, IN: Purdue University, Iowa Cooperative Extension Service. 132 p.

Homer, C.; Dewitz, J.; Fry, J.; Coan, M.; Hossain, N.; Larson, C.; Herold, N.; McKerrow, A.; VanDriel, I., Wickham, J. 2007. **Completion of the 2001 National Land Cover Database for the conterminous United States.** Photogrammetric Engineering and Remote Sensing. 73(4): 337-341.

Honnay, O.; Jacquemyn, H.; Bossuyt, B.; Hermy, M. 2005. **Forest fragmentation effects on patch occupancy and population viability of herbaceous plant species.** New Phytologist. 166: 723-736. http://dx.doi.org/10.1111/j.1469-8137.2005.01352.x.

Huang, C.; Yang, B.; Wylie, B.; Homer, C. 2001. **A strategy for estimating tree canopy density using Landsat 7 ETM+ and high resolution images over large areas.** In: Third International Conference on Geospatial Information in Agriculture and Forestry; November 5-7, 2001; Denver, Colorado: U.S. Department of Interior, Geologic Survey. [CD].

Hunter, M.L., Jr. 2005. **A mesofilter conservation strategy to complement fine and coarse filters.** Conservation Biology. 19(4): 1025-1029. http://dx.doi.org/10.1111/j.1523-1739.2005.00172.x.

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

Iverson, L.R., Prasad, A.N. 1998. **Predicting abundance of 80 tree species following climate change in the eastern United States.** Ecological Monographs. 68(4): 465-485. http://dx.doi.org/10.2307/2657150.

Jakes, P.J. 1980. **The fourth Minnesota forest inventory: area.** Resour. Bull. NC-54. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 37 p.

Jin, S.; Yang, L.; Danielson, P.; Homer, C.; Fry, J.; Xian, G. 2013. **A comprehensive change detection method for updating the National Land Cover Database to circa 2011.** Remote Sensing of Environment. 132: 159-175. http://dx.doi.org/10.1016/j.rse.2013.01.012.

Johnson, P.S.; Shifley, S.R.; Rogers, R. 2002. **The ecology and silviculture of oaks.** CABI Publishing. 503 p. ISBN: 9780851995700.

Jules, E.S.; Kauffman, M.J.; Ritts, W.D.; Carroll, A.L. 2002. **Spread of an invasive pathogen over a variable landscape: a nonnative root rot on Port Orford cedar.** Ecology. 83(11): 3167-3181. http://dx.doi.org/10.2307/3071851.

Kapos, V.; Lysenko, I.; Lesslie, R. 2000. **Assessing forest integrity and naturalness in relation to biodiversity.** Forest Resources Assessment Programme, Working Paper 54. Rome, Italy: Food and Agriculture Organization of the United Nations, Forestry Department. 65 p.

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

Kurtz, C.M. 2013. **An assessment of invasive plant species monitored by the Northern Research Station Forest Inventory and Analysis Program, 2005 through 2010.** Gen. Tech. Rep. NRS-109. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 70 p. http://dx.doi.org/10.2737/NRS-GTR-109.

Langford, W.T.; Gergel, S.E.; Dietterich, T.G.; Cohen, W. 2006. **Map misclassification can cause large errors in landscape pattern indices: examples from habitat fragmentation.** Ecosystems. 9(3): 474-488. http://dx.doi.org/10.1007/s10021-005-0119-1.

Leatherberry, E.C.; Spencer, J.S., Jr.; Schmidt, T.L.; Carroll, M.R. 1995. **An analysis of Minnesota`s fifth forest resources inventory, 1990.** Resour. Bull. NC-165. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 102 p.

Lepczyk, C.A.; Hammer, R.B.; Stewart, S.I.; Radeloff, V.C. 2007. **Spatiotemporal dynamics of housing growth hotspots in the North Central U.S. from 1940 to 2000.** Landscape Ecology. 22: 939-952. http://dx.doi.org/10.1007/s10980-006-9066-2.

Liebhold, A.M.; Gottschalk, K.W.; Muzika, R-M.; Montgomery, M.E.; Young, R.; O'Day, K.; Kelley, B. 1995a. **Suitability of North American tree species to the gypsy moth: a summary of field and laboratory tests.** Gen. Tech. Rep. NE-211. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 34 p.

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

Marschner, F.J. 1930. **The original vegetation of Minnesota.** Map derived from General Land Office field notes. Bureau of Agricultural Economics.

McMahon, G.; Cuffney, T.F. 2000. **Quantifying urban intensity in drainage basins for assessing stream ecological conditions.** Journal of the American Water Resources Association. 36(6): 1247-1261. http://dx.doi.org/10.1111/j.1752-1688.2000.tb05724.x.

McRoberts, R.E. 1999. **Joint annual forest inventory and monitoring system: the North Central perspective.** Journal of Forestry. 97: 21-26.

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

McWilliams, W.H.; Westfall, J.A.; Brose, P.H.; Dey, D.C.; Hatfield, M.; Johnson, K.; Laustsen, K.M.; Lehman, S.L.; Morin, R.S.; Nelson, M.D.; Ristau, T.E.; Royo, A.A.; Stout, S.L.; Willard, T; Woodall, C.W. 2015. **A regeneration indicator for Forest Inventory and Analysis: history, sampling, estimation, analytics, and potential use in the Midwest and Northeast United States.** Gen. Tech. Rep. NRS-148. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 74 p. http://dx.doi.org/10.2737/NRS-GTR-148.

Miles, P.D.; Heinzen, D.; Meilke, M.E.; Woodall, C.W.; Butler, B.J.; Piva, R.J.; Meneguzzo, D.M.; Perry, C.H.; Gormanson, D.D.; Barnett, C.J. 2011. **Minnesota's Forests 2008.** Resour. Bull. NRS-50. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 67 p. [DVD included].

Miles, P.D.; Jacobson, K.; Brand, G.J.; Jepsen, E.; Meneguzzo, D.; Mielke, M.E.; Olson, C.; Perry, C.H.; Piva, R.; Wilson, B.T.; Woodall, C. 2007. **Minnesota's forests 1999-2003 (Part A).** Resour. Bull. NRS-12A. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 92 p.

Miles, P.D.; Smith, W.B. 2009. **Specific gravity and other properties of wood and bark for 156 tree species found in North America.** Res. Pap. NRS-38. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 35 p. http://dx.doi.org/10.2737/NRS-RN-38.

Minnesota Department of Agriculture. 2015. **Gypsy moth quarantine.** http://www.mda.state.mn.us/gmquarantine (accessed April 2, 2015).

Minnesota Department of Natural Resources, ed. 2005. **Tomorrow's habitat for the wild and rare: an action plan for Minnesota wildlife.** St. Paul, MN: Minnesota Department of Natural Resources. http://archive.leg.state.mn.us/docs/2006/other/060316/www.dnr.state.mn.us/cwcs/strategy.html (accessed March 16, 2015).

Minnesota Department of Natural Resources. 2015a. **The DNR data deli.** http://deli.dnr.state.mn.us/ (accessed March 16, 2015).

Minnesota Department of Natural Resources. 2015b. **Peatlands, bogs and fens.** http://www.dnr.state.mn.us/snas/coniferous_peatlands.html (accessed May 5, 2015).

Montreal Process. 1995. **Criteria and indicators for the conservation and sustainable management of temperate and boreal forests.** Hull, Quebec: Canadian Forest Service, 27 p.

Moody, A.; Woodcock, C.E. 1995. **The influence of scale and the spatial characteristics of landscapes on land-cover mapping using remote sensing.** Landscape Ecology. 10(6): 363-379. http://dx.doi.org/10.1007/bf00130213.

Morin, R.S.; Randolph, K.C.; Steinman, J. 2015. **Mortality rates associated with crown health for eastern forest tree species.** Environmental Monitoring and Assessment. 187: 87. http://dx.doi.org/10.1007/s10661-015-4332-x.

NatureServe. [N.d.]. **Explorer® online encyclopedia of life.** Arlington, VA: NatureServe. http://explorer.natureserve.org/servlet/NatureServe?init=Species (accessed February 17, 2011).

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

O'Connell, B.M.; LaPoint, E.B.; Turner, J.A.; Ridley, T.; Pugh, S.A.; Wilson, A.M.; Waddell, K.L.; Conkling, B.L. 2014. **The Forest Inventory and Analysis database: database description and user guide Ver. 6.0.1 for Phase 2.** Washington, DC: U.S. Department of Agriculture, Forest Service. 748 p. Available at http://www.fia.fs.fed.us/library/database-documentation/.

Oswalt, S.N.; Smith, W.B.; Miles, P.D.; Pugh, S.A. 2014. **Forest Resources of the United States, 2012: a technical document supporting the Forest Service 2010 update of the RPA Assessment.** Gen. Tech. Rep. WO-91. Washington, DC: U.S. Department of Agriculture, Forest Service, Washington Office. 218 p.

Palik, B.; Johnson, J. 2007. **Constraints on pine regeneration in northern Minnesota: causes and potential solutions.** Final report to the north central landscape committee. St. Paul, MN: Minnesota Forest Resources Council. 37 p. http://mn.gov/frc/documents/council/MFRC_Constraints_Red_Pine_Regen_2007-11-07_Report.pdf (accessed February, 2015).

Pimentel, D.; Lach, L.; Zuniga, R.; Morrison, D. 2000. **Environmental and economic costs of nonindigenous species in the United States.** BioScience. 50(1): 53-65. http://dx.doi.org/10.1641/0006-3568(2000)050[0053:eaecon]2.3.co;2.

Poland, T.M.; Haack, R.A. 2003. **Exotic forest insect pests and their impact on forest management.** In: Proceedings of the Society of American Foresters, 2002 national convention; 2002 October 5-9; Winston-Salem, NC. SAF Publ. 03-01. Bethesda, MD: Society of American Foresters: 132-141.

Pugh, S.A.; Pedersen, L.D.; Heym, D.C.; Piva, R.J.; Woodall, C.W.; Barnett, C.J.; Kurtz, C.M.; Moser, W.K. 2012. **Michigan's Forests 2009.** Resour. Bull. NRS-66. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p. [DVD included]. http://dx.doi.org/10.2737/NRS-RB-66.

Radeloff, V.C.; Hammer, R.B.; Stewart, S.I.; Fried, J.S.; Holcomb, S.S.; McKeefry, J.F. 2005. **The wildland urban interface in the United States.** Ecological Applications. 15: 799-805. http://dx.doi.org/10.1890/04-1413. http://dx.doi.org/10.1890/04-1413.

Riitters, K.H.; Wickham, J.D. 2003. **How far to the nearest road?** Frontiers in Ecology and the Environment. 1(3): 125-129. http://dx.doi.org/10.2307/3867984.

Riva-Murray, K.; Riemann, R.; Murdoch, P.; Fischer, J.M.; Brightbill, R.A. 2010. **Landscape characteristics affecting streams in urbanizing regions of the Delaware River Basin (New Jersey, New York, and Pennsylvania, US.).** Landscape Ecology. 25(10): 1489-1503. http://dx.doi.org/10.1007/s10980-010-9513-y.

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

Russell, F.L.; Zippin, D.B.; Fowler, N.L. 2001. **Effects of white-tailed deer *(Odocoileus virginianus)* on plants, plants populations and communities: a review.** The American Midland Naturalist. 146(1): 1-26. http://dx.doi.org/10.1674/0003-0031(2001)146[0001:eowtdo]2.0.co;2.

Russell, M.B.; Woodall, C.W.; D'Amato, A.W.; Fraver, S.; Bradford, J.B. 2014a. **Linking climate change and downed woody debris decomposition across forests of the eastern United States.** Biogeosciences. 11: 6417-6425. http://dx.doi.org/10.5194/bg-11-6417-2014.

Russell, M.B.; Woodall, C.W.; Fraver, S.; D'Amato, A.W.; Domke, G.M.; Skog, K.E. 2014b. **Residence time and rate of decay for downed woody debris biomass/carbon in eastern US forests.** Ecosystems. 17: 765-777. http://dx.doi.org/10.1007/s10021-014-9757-5.

Scott, C.T.; Bechtold, W.A.; Reams, G.A.; Smith, W.D.; Westfall, J.A.; Hansen, M.H.; Moisen, G.G. 2005. **Sample-based estimators used by the Forest Inventory and Analysis national information management system.** In: Bechtold, W.A.; Patterson, P.L., eds. The enhanced Forest Inventory and Analysis program—national sampling design and estimation procedures. Gen. Tech. Rep. SRS-GTR-80. Asheville, NC: U.S. Department of Agriculture, Forest Service: 43-67.

Seilheimer, T.S.; Zimmerman, P.L.; Stueve, K.M.; Perry, C.H. 2013. **Landscape-scale modeling of water quality in the Lake Superior and Lake Michigan watersheds: How useful are forest-based indicators?** Journal of Great Lakes Research. 39(2): 211–223. http://dx.doi.org/10.1016/j.jglr.2013.03.012.

Shao, G.; Wu, J. 2008. **On the accuracy of landscape pattern analysis using remote sensing data.** Landscape Ecology. 23(5): 505-511. http://dx.doi.org/10.1007/s10980-008-9215-x.

Shifley, S.R.; Moser, W.K., eds. 2016. **Future forests of the northern United States.** Gen. Tech. Rep. NRS-151. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 388 p.

Shifley, S.R.; Moser, W.K.; Nowak, D.J.; Miles, P.D.; Butler, B.J.; Aguilar, F.X.; DeSantis, R.D.; Greenfield, E.J. 2014. **Five anthropogenic factors that will radically alter forest conditions and management needs in the Northern United States.** Forest Science. 60(5): 914-925. http://dx.doi.org/10.5849/forsci.13-153.

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. **The practice of silviculture: applied forest ecology.** 9th edition. New York, NY: John Wiley & Sons, Inc. 537 p. ISBN: 9780471109419.

Smith, W.B. 1991. **Assessing removals for North Central forest inventories.** Resour. Pap. NC-299. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 48 p.

Society of American Foresters. [N.d.]. **The dictionary of forestry.** Bethesda, MD: Society of American Foresters. http://dictionaryofforestry.org (accessed February 9, 2012).

Steinman, J. 2000. **Tracking the health of trees over time on forest health monitoring plots.** In: Hansen, M.; Burk, T., eds. Proceedings, integrated tools for natural resources inventories in the 21st century; 1998 August 16-20; Boise, ID. Gen. Tech. Rep. NC-212. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Research Station: 334-339.

Stone, R.N. 1966. **A third look at Minnesota's timber.** Resour. Bull. NC-1. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station. 70 p.

Theobald, D.M. 2005. **Landscape patterns of exurban growth in the USA from 1980 to 2020.** Ecology and Society. 10(1): 34.

U.S. Census Bureau. 2000. **United States Census 2000.** Washington, DC: U.S. Department of Commerce, Bureau of the Census. http://www.census.gov/main/www/cen2000.html (accessed 2006).

U.S. Census Bureau. 2010. **United States Census 2010.** Washington, DC: U.S. Department of Commerce, Bureau of the Census. www.census.gov/2010census/ (accessed January 2015).

U.S. Environmental Protection Agency [U.S. EPA]. 2015. **Inventory of U.S. greenhouse gas emissions and sinks: 1990–2013.** EPA 430-R-15-004. Washington, DC: U.S. Environmental Protection Agency, Office of Atmospheric Programs. http://www3.epa.gov/climatechange/Downloads/ghgemissions/US-GHG-Inventory-2015-Main-Text.pdf (accessed March 10, 2016).

U.S. Forest Service. 2007. **Forest inventory and analysis national core field guide: field data collection procedures for Phase 3 plots, Ver. 4.0.** Washington, DC: U.S. Department of Agriculture, Forest Service. Available at http://www.fia.fs.fed.us/library/field-guides-methods-proc/ (accessed April 9, 2015).

U.S. Forest Service. 2012. **Forest Inventory and Analysis national core field guide: volume I—field data collection procedures for Phase 2 plots, Ver. 6.0.** Washington, DC: U.S. Department of Agriculture, Forest Service. Available at http://www.fia.fs.fed.us/library/field-guides-methods-proc/ (accessed April 9, 2015).

U.S. Forest Service. 2014a. **The Forest Inventory and Analysis database: database description and user guide Ver. 6.0.1 for Phase 3.** Washington, DC: U.S. Department of Agriculture, Forest Service. 182 p. Available at http://www.fia.fs.fed.us/library/database-documentation/ (accessed April 9, 2015).

U.S. Forest Service. 2014b. F**orest Inventory and Analysis national core field guide: Northern Research Station edition, volume I supplement—field data collection procedures for P2+ plots, Ver. 6.0.** Newtown Square, PA: U.S. Department of Agriculture, Forest Service.

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

Waters, T. 1977. **The streams and rivers of Minnesota.** Minneapolis, MN: University of Minnesota Press. 373 p.

Wear, D.N.; Liu, R.; Foreman, M.J.; Sheffield, R.M. 1999. **The effects of population growth on timber management and inventories in Virginia.** Forest Ecology and Management. 118: 107-115. http://dx.doi.org/10.1016/s0378-1127(98)00491-5.

White, M.A. 2012. **Long-term effects of deer browsing: composition, structure, and productivity in a northeastern Minnesota old-growth forest.** Forest Ecology and Management. 269: 222-228. http://dx.doi.org/10.1016/j.foreco.2011.12.043.

Wilcox, B.A.; Murphy, D.D. 1985. **Conservation strategy: the effects of fragmentation on extinction.** American Naturalist. 125: 879-887. http://dx.doi.org/10.1086/284386.

Wilson, B.T.; Lister, A.J.; Riemann, R.I. 2012. **A nearest-neighbor imputation approach to mapping tree species over large areas using forest inventory plots and moderate resolution raster data.** Forest Ecology and Management. 271: 182-198. http://dx.doi.org/10.1016/j.foreco.2012.02.002.

Woodall, C.W.; Conkling, B.L.; Amacher, M.C.; Coulston, J.W.; Jovan, S.; Perry, C.H.; Schulz, B.; Smith, G.C.; Will-Wolf, S. 2010. **The Forest Inventory and Analysis database Ver. 4.0: database description and users manual for Phase 3.** Gen. Tech. Rep. NRS-61. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 180 p. http://dx.doi.org/10.2737/NRS-GTR-61.

Woodall, C.W.; Monleon, V.J. 2008. **Sampling protocol, estimation, and analysis procedures for the down woody materials indicator of the FIA program.** Gen. Tech. Rep. NRS-22. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 68 p. http://dx.doi.org/10.2737/NRS-GTR-22.

Woodall, C.W.; Walters, B.F.; Oswalt, S.N.; Domke, G.M.; Toney, C.; Gray, A.N. 2013. **Biomass and carbon attributes of downed woody materials in forests of the United States.** Forest Ecology and Management. 305: 48-59. http://dx.doi.org/10.1016/j.foreco.2013.05.030.

Work, T.T.; McCullough, D.G.; Cavey, J.F.; Komsa, R. 2005. **Arrival rate of nonindigenous insect species into the United States through foreign trade.** Biological Invasions. 7: 323-332. http://dx.doi.org/10.1007/s10530-004-1663-x.

Zon, R. 1935. **The forests of Minnesota: areas and types.** Forest Survey No.1. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station. 25 p.

Appendix 1.—List of tree species, greater than or equal to 5 inches in diameter, found on FIA inventory plots, Minnesota, 2009-2013

Common name	Genus	Species
Balsam fir	*Abies*	*balsamea*
Boxelder	*Acer*	*negundo*
Black maple	*Acer*	*nigrum*
Red maple	*Acer*	*rubrum*
Silver maple	*Acer*	*saccharinum*
Sugar maple	*Acer*	*saccharum*
Mountain maple	*Acer*	*spicatum*
Serviceberry spp.	*Amelanchier*	spp.
Yellow birch	*Betula*	*alleghaniensis*
River birch	*Betula*	*nigra*
Paper birch	*Betula*	*papyrifera*
American hornbeam, musclewood	*Carpinus*	*caroliniana*
Bitternut hickory	*Carya*	*cordiformis*
Shagbark hickory	*Carya*	*ovata*
Hackberry	*Celtis*	*occidentalis*
Hackberry spp.	*Celtis*	spp.
Hawthorn spp.	*Crataegus*	spp.
Russian-olive	*Elaeagnus*	*angustifolia*
White ash	*Fraxinus*	*americana*
Black ash	*Fraxinus*	*nigra*
Green ash	*Fraxinus*	*pennsylvanica*
Butternut	*Juglans*	*cinerea*
Black walnut	*Juglans*	*nigra*
Eastern redcedar	*Juniperus*	*virginiana*
Tamarack (native)	*Larix*	*laricina*
Apple spp.	*Malus*	spp.
White mulberry	*Morus*	*alba*
Red mulberry	*Morus*	*rubra*
Mulberry spp.	*Morus*	spp.
Eastern hophornbeam	*Ostrya*	*virginiana*
White spruce	*Picea*	*glauca*
Black spruce	*Picea*	*mariana*
Blue spruce	*Picea*	*pungens*
Jack pine	*Pinus*	*banksiana*
Austrian pine	*Pinus*	*nigra*
Red pine	*Pinus*	*resinosa*
Eastern white pine	*Pinus*	*strobus*
Scotch pine	*Pinus*	*sylvestris*
Balsam poplar	*Populus*	*balsamifera*
Eastern cottonwood	*Populus*	*deltoides*

(Appendix continued on next page.)

(Appendix 1. continued)

Common name	Genus	Species
Bigtooth aspen	*Populus*	*grandidentata*
Cottonwood and poplar spp.	*Populus*	spp.
Quaking aspen	*Populus*	*tremuloides*
American plum	*Prunus*	*americana*
Pin cherry	*Prunus*	*pensylvanica*
Black cherry	*Prunus*	*serotina*
Cherry and plum spp.	*Prunus*	spp.
Chokecherry	*Prunus*	*virginiana*
White oak	*Quercus*	*alba*
Swamp white oak	*Quercus*	*bicolor*
Northern pin oak	*Quercus*	*ellipsoidalis*
Bur oak	*Quercus*	*macrocarpa*
Northern red oak	*Quercus*	*rubra*
Black oak	*Quercus*	*velutina*
Black locust	*Robinia*	*pseudoacacia*
Peachleaf willow	*Salix*	*amygdaloides*
Bebb willow	*Salix*	*bebbiana*
Black willow	*Salix*	*nigra*
Willow spp.	*Salix*	spp.
Mountain-ash spp.	*Sorbus*	spp.
Northern white-cedar	*Thuja*	*occidentalis*
American basswood	*Tilia*	*americana*
American elm	*Ulmus*	*americana*
Siberian elm	*Ulmus*	*pumila*
Slippery elm	*Ulmus*	*rubra*
Rock elm	*Ulmus*	*thomasii*

Appendix 2.—FIA forest type to Minnesota Department of Natural Resources (DNR) cover type crosswalk

FIA forest type code	FIA forest type/forest-type group	Minnesota DNR forest type
100	**White/red/jack pine group**	White/red/jack pine group
101	Jack pine	Jack pine
102	Red pine	Red pine
103	Eastern white pine	Eastern white pine
120	**Spruce/fir group**	Spruce/fir group
121	Balsam fir	Balsam fir
122	White spruce	White spruce
125	Black spruce	Black spruce
126	Tamarack	Tamarack
127	Northern white-cedar	Northern white-cedar
181	Retired (eastern redcedar)	Eastern redcedar
380	**Exotic softwoods group**	Other softwoods
381	Scotch pine	Other softwoods
400	**Oak/pine group**	Red pine
401	Eastern white pine-northern red oak-white ash	Eastern white pine
402	Eastern redcedar-hardwood	Eastern redcedar
409	Other pine-hardwood	Red pine
500	**Oak/hickory group**	Oak
503	White oak-red oak-hickory	Oak
504	White oak	Oak
505	Northern red oak	Oak
509	Bur oak	Oak
519	Red maple-oak	Northern hardwoods
520	Mixed upland hardwoods	Northern hardwoods
700	**Elm/ash/cottonwood group**	Lowland hardwoods
701	Black ash-American elm-red maple	Lowland hardwoods
702	River birch-sycamore	Birch
703	Cottonwood	Cottonwood/willow
704	Willow	Cottonwood/willow
705	Sycamore-pecan-American elm	Lowland hardwoods
706	Sugarberry-hackberry-elm-green ash	Lowland hardwoods
707	Silver maple-American elm	Lowland hardwoods
708	Red maple-lowland	Lowland hardwoods
709	Cottonwood-willow	Cottonwood/willow
800	**Maple/beech/birch group**	Northern hardwoods
801	Sugar maple-beech-yellow birch	Northern hardwoods
805	Hard maple-basswood	Northern hardwoods
807	Retired (Elm-ash-locust)	Northern hardwoods
809	Red maple-upland	Northern hardwoods

(Appendix continued on next page.)

(Appendix 2. continued)

FIA forest type code	FIA forest type/forest-type group	Minnesota DNR forest type
900	**Aspen/birch group**	Aspen
901	Aspen	Aspen
902	Paper birch	Birch
904	Balsam poplar	Balsam poplar
999	Nonstocked	Nonstocked
	All other types	Other

Miles, Patrick D.; VanderSchaaf, Curtis L.; Barnett, Charles; Butler, Brett J.; Crocker, Susan J.; Gormanson, Dale; Kurtz, Cassandra M.; Lister, Tonya W.; McWilliams, William H.; Morin, Randall S.; Nelson, Mark D.; Perry, Charles H.; Riemann, Rachel I.; Smith, James E.; Walters, Brian F.; Westfall, James A.; Woodall, Christopher W. 2016. **Minnesota Forests 2013.** Resource Bulletin NRS-104. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 134 p.

The third full annual inventory of Minnesota forests reports 17.4 million acres of forest land with an average live tree volume of 1,096 cubic feet per acre. Forest land is dominated by the aspen forest type, which occupies 29 percent of the total forest land area. Twenty-eight percent of forest land consists of sawtimber, 35 percent poletimber, 36 percent sapling/seedlings, and 1 percent is nonstocked. The average annual net growth of live trees on forest land is approximately 398 million cubic feet per year while average annual removals are only 207 million cubic feet per year. Additional forest attribute and forest health information is presented, along with information on agents of change including changing land use patterns and the introduction of nonnative plants, insects, and disease. Information from the Private Woodland Owner and Timber Products Output surveys is included along with 50-year projections from the Northern Forest Futures study. Detailed information on forest inventory methods, data quality estimates, and important resource statistics are available online at http://dx.doi.org/10.2737/NRS-RB-104.

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

Northern Research Station

www.nrs.fs.fed.us