Minnesota's Forests 2008

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Abstract

The second full annual inventory of Minnesota's forests reports 17 million acres of forest land with an average volume of more than 1,000 cubic feet per acre. Forest land is dominated by the aspen forest type, which occupies nearly 30 percent of the total forest land area. Twenty-eight percent of forest land consists of sawtimber, 35 percent poletimber, 35 percent sapling/seedlings, and 2 percent is nonstocked. The average annual net growth of live trees on forest land from 2004 to 2008 is approximately 435 million cubic feet year while average annual removals is only 288 million cubic feet per year. Removals exceeds growth for some commercial species. 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. Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found on the Statistics and Quality Assurance DVD on the inside back cover of this report.

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Foreword

Minnesota is home to three major ecosystems: prairies in the west, 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's 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's forest resources in 1935, 1953, 1962, 1977, 1990, 2003, and 2008. 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, completed in 2008, covers 2004 to 2008. With complete remeasurement of annual inventory plots, we are able to produce better estimates of growth, mortality, and removals and to produce detailed reports on ground land use change.

This report provides an overview of the current condition and health of Minnesota's 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's forests.

Contents

Highlights

On the Plus Side

Minnesota ranks 14th among the 50 states in land area, 21st in forest land, 15th in area of Federal forest land, and 1st in area of state/county/local government land.

Forest land accounts for 17.0 million acres or one-third of the land area in Minnesota. Most of Minnesota's forest land (92 percent or 15.6 million acres) is timberland.

The area of forest land has increased by nearly 5 percent since 2003 due largely to the reversion of nonforest land (primarily marsh and cropland) to forest land.

The total oven-dry biomass of all live trees on timberland increased from 346 million tons in 1977 to 407 million tons in 2003 and to 428 million tons in 2008. Total live-tree oven-dry biomass on forest land increased from 438 million tons in 2003 to 458 million tons in 2008.

Average annual net growth of growing stock on timberland, from 2003 to 2008, was 417 million cubic feet or roughly 3 percent of the total growing-stock volume in 2008, a slight increase over the 404 million cubic feet of average annual net growth from 1990 to 2003.

Average annual removals of growing stock on timberland, from 2003 to 2008, was 294 million cubic feet, or roughly 2 percent of the total growing-stock volume in 2008, an increase over the 249 million cubic feet of average annual removals from 1990 to 2003.

The growth-to-removals ratio of 1.4 for 2003 to 2008 indicates that net growth is 1.4 times greater than removals and that growing-stock volume is increasing.

Fuel loadings of down woody materials are not exceedingly high in Minnesota compared to areas of high fire hazard in western states.

In Minnesota, for every 100 live trees more than 5 inches in diameter on forest land, there are 14 standing dead trees that provide valuable wildlife habitat.

More than 40,000 people are directly employed in the forest sector of the economy including approximately 30,000 people in wood and paper product manufacturing. The forest products industry is the fourth largest manufacturing sector in Minnesota.

Issues to Watch

Almost half (48 percent) of the forest land in Minnesota is less than fully stocked. One-third of the forest land has medium stocking, 13 percent is poorly stocked, and 2 percent is nonstocked.

The majority of sawtimber is in lower valued trees (grades 3 and less) for both hardwoods (58 percent) and softwoods (63 percent). Tree grade 2 represents 30 percent of total hardwood volume and 11 percent of softwood volume. The most valuable lumber is in grade 1, which constitutes 11 percent and 26 percent of hardwood and softwood volumes, respectively.

The average annual mortality of growing stock on timberland from 2003 to 2008 was 243 million cubic feet; this is equal to 1.7 percent of the total growing-stock volume on timberland in 2008 – a rate significantly higher than the 1.2 percent reported in 1977 but slightly less than the 1.8 percent reported in 2003.

High mortality rates have led to a 5-percent decline in the volume of balsam fir, a 3-percent decline in quaking aspen and a 3-percent decline in the volume of paper birch. Mortality rates should decline for aspen over the next inventory due to forest management efforts to regenerate older senescent stands.

Smokey Hills State Forest, Elena Teich

European gypsy moth egg masses were discovered in several locations including just 1 mile from the Boundary Waters Canoe Area Wilderness (BWCAW).

The emerald ash borer has been found in St. Paul, MN, and threatens all species of ash.

Sixty-seven introduced or invasive plant species were found on 184 vegetation diversity plots. Forty-five percent of the plots had nonnative species.

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

Common Loon, Bear Head Lake State Park. Photo used with permission of Minnesota Dept. of Natural Resources.

A Beginners Guide to Forest Inventory

What is a tree?

We know a tree when we see one and we can agree on some common tree attributes. Trees are perennial woody plants with central stems and distinct crowns. In general, the Forest Inventory and Analysis (FIA) program of the U.S. Department of Agriculture, Forest Service defines a tree as any perennial woody plant species that can attain a height of 15 feet at maturity. In 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 "Minnesota's Forests 2008: Statistics and Quality Assurance," on the DVD in the inside back cover pocket of this bulletin.

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 often determines the allocation of funding for certain State and Federal programs. Forest managers want more land classified as forest land, and range managers want more land classified as prairie. Somewhere you have to draw the line.

FIA defines forest land as land that is at least 10 percent stocked by trees of any size or formerly having had such tree cover and 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, 92 percent of the forest land is timberland, 5 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 withdrawn from timber utilization through legislation or administrative regulation (most of the reserved forest land in Minnesota is in the Boundary Waters Canoe Area Wilderness and Voyageurs 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.

Before 1999 only trees on timberland plots were measured in Minnesota. Therefore, while we can report volume on timberland for those inventories, we can't report volume on forest land. Under the new annual inventory system, trees were measured on all forest land so forest volume estimates can be produced. Because these annual plots have been remeasured upon completion of the second annual inventory in 2008, we are now able to report growth, removals and mortality on all forest land, not just on timberland.

How many trees are in Minnesota?

There are approximately 2.3 billion trees on Minnesota's forest land (give or take a few million) that are at least 5 inches in diameter as measured at 4.5 feet above the ground. We don't know the exact number because we measured only about 1 out of every 18,000 trees. In all, 120,131 trees 5 inches and larger were sampled on 6,139 forested plots.[1]

[1] During the 2008 inventory of Minnesota (from 2004 to 2008), we measured one 1/6-acre plot for approximately every 3,000 acres of forest land.

How do we estimate a tree's volume?

FIA has typically expressed volumes in cubic-feet. But, in Minnesota, wood is more commonly measured in cords (a stack of logs 8 feet long 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 these data by species group. Using these regression equations, we can produce individual-tree volume estimates based on species, diameter, and tree site index.

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

How much does a tree weigh?

The U.S. Forest Service's 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 to derive estimates of merchantable tree biomass (the weight of the bole). To estimate live biomass, we have to add in the stump (Raile 1982) and limbs and bark (Heath et al. 2009). We do not currently report the live biomass of roots or foliage.

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

How do we estimate all the forest carbon pools?

FIA does not measure the carbon in standing trees, let alone carbon in belowground pools. FIA 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 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 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 plot classification variables such as forest type and stand-size class. Some of these changes make it inappropriate to directly compare the 2008 and 2003 annual inventory tables with periodic inventories published for 1935, 1953, 1962, 1977, and 1990.

The biggest change in inventories was the change in plot design. In an effort toward national consistency, a new 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 and 2008 inventories used 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 – plots that were measured in 1977 and projected forward using the STEMS (Belcher et al. 1982) growth model. This was done to save money by reducing the number of undisturbed plots that were sent to the field for remeasurement, 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 all live volume on timberland by about 6 percent.

A word of caution on suitability and availability…

FIA does not attempt to identify which lands are suitable or available for timber harvesting, particularly because 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.

Forest Features

Schoolcraft State Park. Photo used with permission of Minnesota Dept. of Natural Resources.

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's 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).

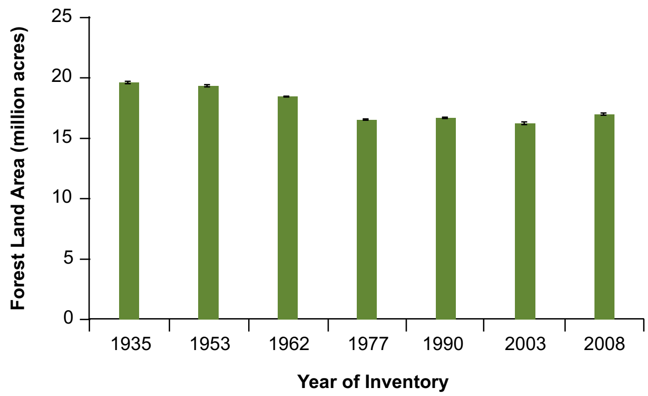

Figure 1.—Area of forest land in Minnesota by inventory year.[2]

What we found

Minnesota's forest land area is currently estimated at 17.0 million acres or a little more than one-third of the land area of the State (Fig. 1).

The pre-settlement 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. Since then, the area of forest land in Minnesota has been relatively stable with a slight increase in 1990 followed by a slight decrease in 2003 and a 4.7-percent increase in 2008. The slight decrease in forest area from 1990 to 2003 may be due to the change in plot design.

Changes in the area of forest land vary by region. Eighty-nine percent of Minnesota's forest land lies above the 46th parallel, which runs through the town of Hinckley, MN (Fig. 2). Above this line, the area of forest land declined by 1.2 percent, from 15.2 million acres in 1977 to 15.0 million in 2008. Below this line, the area of forest land increased by about 49 percent, from 1.3 million acres in 1977 to 1.9 million acres in 2008.

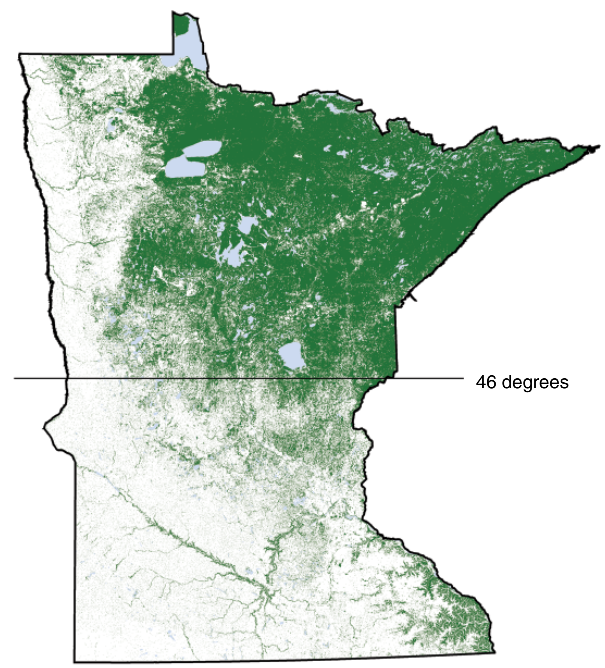

Figure 2.—Forest area from National Land Cover Dataset.

[2] The error bar atop each bar in Figure 1 provides a measure of reliability of these figures. In 2008 there was a two out of three chance that if a 100-percent inventory had been taken, using the same methods, the result would have been within the limits indicated by the error bar – 16,990.3 thousand acres plus or minus 91.75 thousand acres.

The area of timberland was estimated at 14.7 million acres in both 1990 and 2003. From 2003 to 2008, the area of timberland increased by more than 800,000 acres to 15.6 million acres.

Overall, Minnesota is one-third forest land (Fig. 3), which is low for the Lake States (Table 1) but average for the United States. Minnesota ranks 14th among the 50 states in land area, 21st in forest land, and 18th in area of timberland.

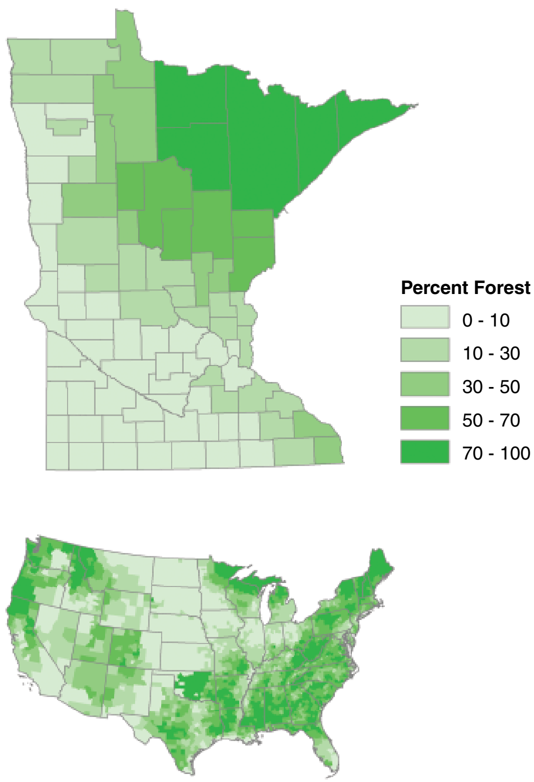

Figure 3.—Percent of land forested by county, Minnesota and United States, 2008.

Table 1.—Minnesota in context: Area of forest land

Geographic Area	Percent Forest Land
World (FAO 2006)	30
North America (FAO 2006)	33
United States (Smith et al. 2009)	33
Lake States (MN, MI, WI)	43
Minnesota	33

What this means

The area and extent of Minnesota's forests decreased from the first forest inventory in 1935 through the fourth inventory in 1977. Since then, much of the losses to forest area have been offset by the reversion of marsh, marginal farmland, and pasture land to forest. The slight increase in forest land area from 1977 to 1990 was due in part to the Federal Conservation Reserve Program. 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.

Increases in the area of timberland between 1977 and 2008 were due in part to changing site productivity estimates. The area of other forest land has declined substantially over the years, from 1.9 million acres in 1977 to 840,000 acres in 1990, 528,000 acres in 2003, and 506,000 acres in 2008. Nearly half of this acreage decrease in other forest land was due to conversion to nonforest land and the other half was due to conversion to timberland. Since 1977, nearly 700,000 acres once classified as other forest land have been reclassified as timberland.

Forest Type Distribution

Background

Minnesota is at the confluence of three ecoprovinces (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.

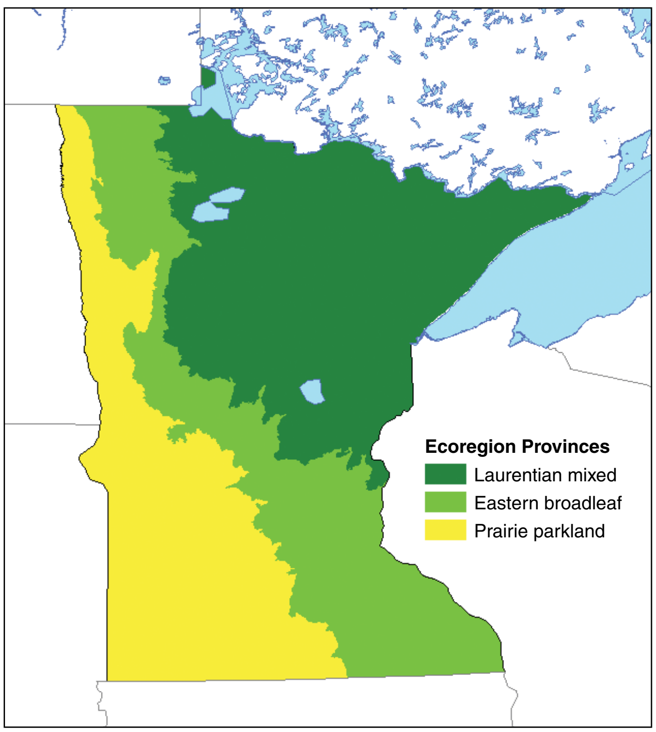

Figure 4.—Bailey's ecoregion provinces of Minnesota.

What we found

Information from forest inventory plots was combined with Modis imagery to produce a forest type map (Fig. 5). 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. The result was a continuous map where aspen, pine, and spruce/fir types predominate in the north while the oak and elm/ash/cottonwood types predominate in the south.

The top 12 forest types in Minnesota account for 80 percent of the forest land (Fig. 6). Aspen is the largest forest type in Minnesota, accounting for 30 percent of the State's forest land (5.0 million acres), followed by the black spruce type at 9 percent and the tamarack type at 6 percent.

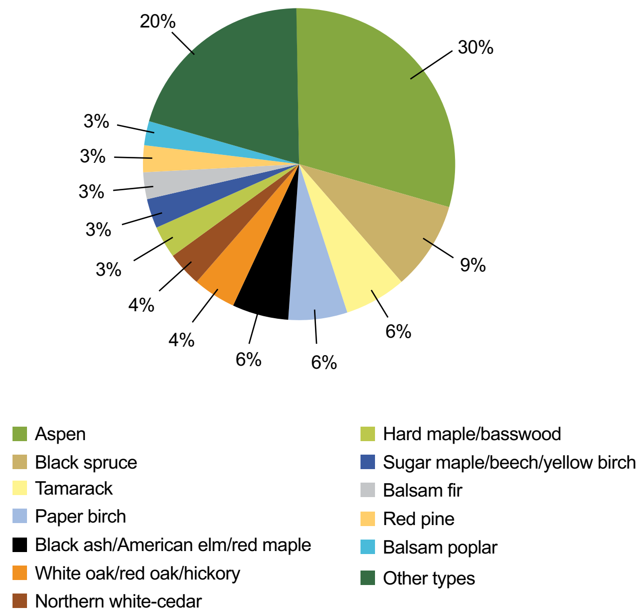

Figure 6.—Proportion of forest land area by forest type, Minnesota, 2008.

What this means

Softwood forest types are concentrated in the Laurentian Mixed 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 softwood type.

The northern reaches of the Eastern Broadleaf province are dominated by the aspen and maple 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 type.

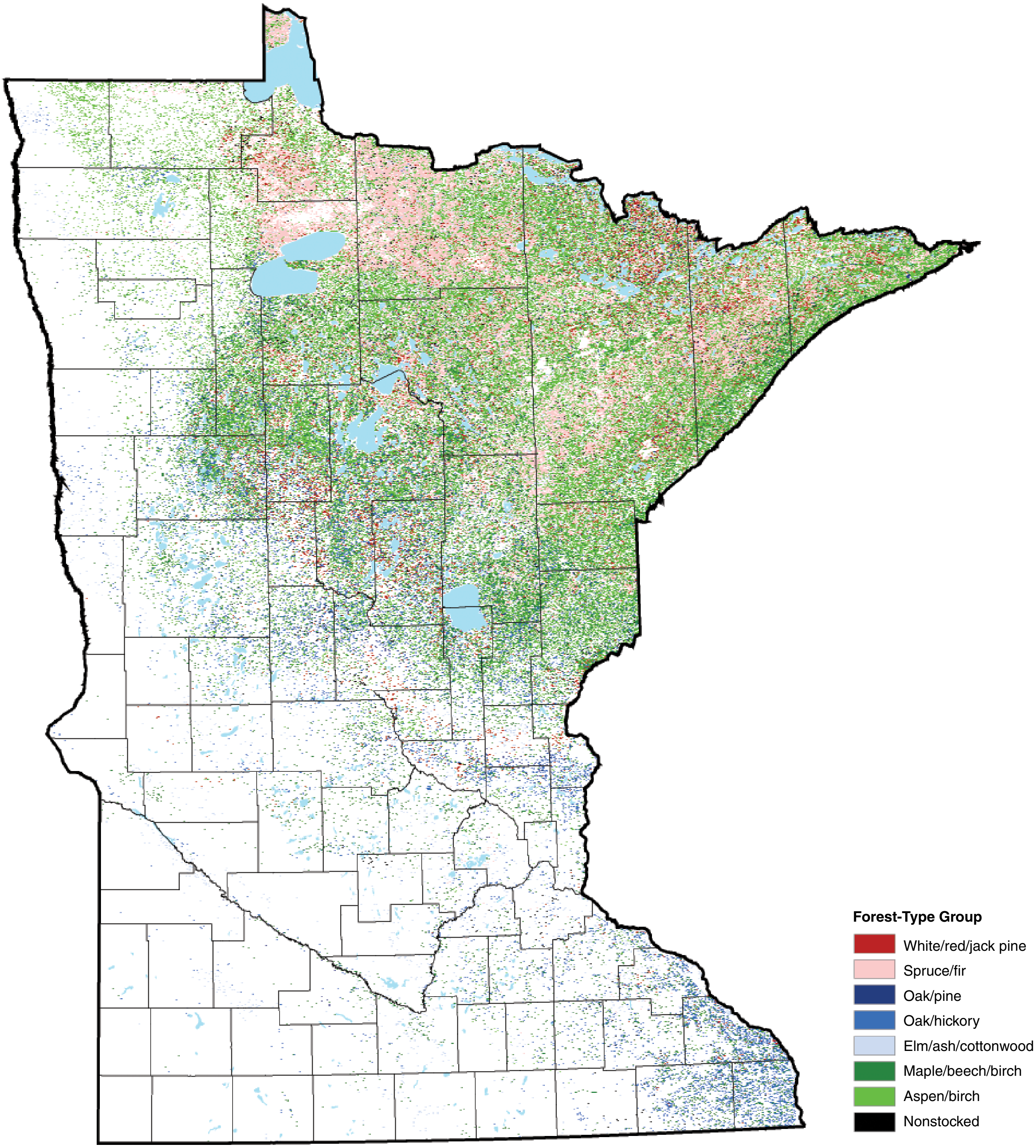

Figure 5.—Forest types of Minnesota, 2008.

Forest Ownership

Background

Forest ownership has a profound impact on how land is managed. 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.

What we found

Nearly 56 percent of Minnesota's 17 million acres of forest land is in public ownership (Figs. 7, 8). The State of Minnesota owns 21 percent, county and local governments own 18 percent, and, the Federal Government administers 17 percent of Minnesota's forest land. 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 Wilderness (BWCAW) (Fig. 9).

The remaining 44 percent of Minnesota's forest land is in private ownership. Non-industrial private forest land owners own 37 percent of the forest land in Minnesota. The remaining 7.4 percent of Minnesota's forest land is owned by forest industry and corporations compared to 10.4 percent in Wisconsin and 14.8 percent in Michigan. More than three-fourths (77.8 percent)

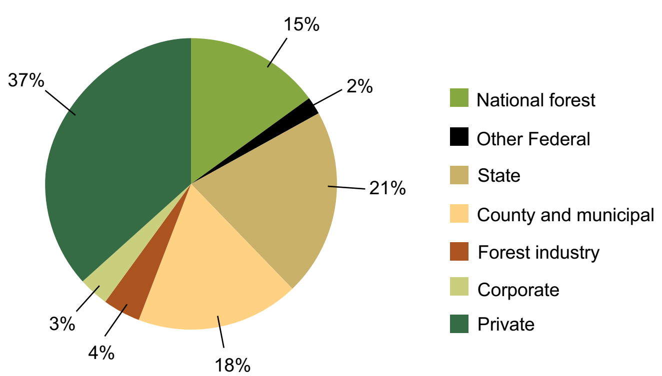

Figure 7.—Forest land by ownership or administering governmental unit, Minnesota, 2008.

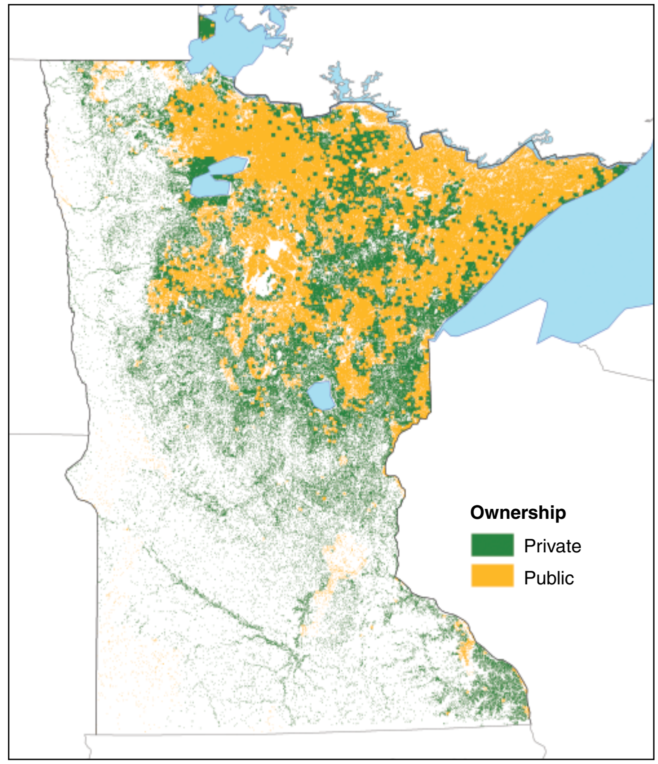

Figure 8.—Public and private forest land ownership, Minnesota, 2008.

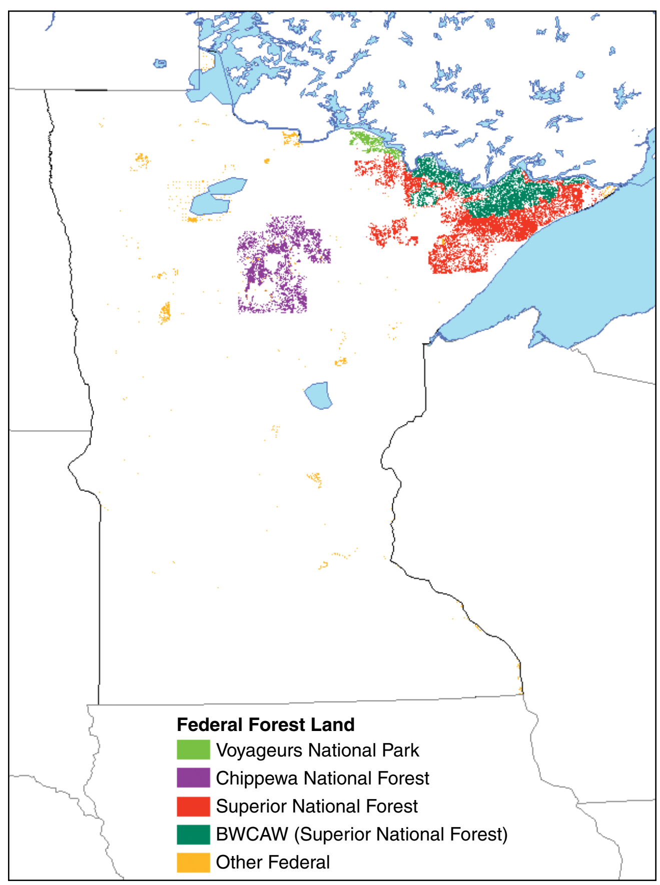

Figure 9.—Federally administered forest lands of Minnesota, 2008.

of forest industry and corporate lands are located in just four counties (Itasca, Koochiching, Lake, and St. Louis). Even in these four counties, forest industry and corporations own only 13.1 percent of the forest land.

What this means

Management objectives vary by owner. Harvest rates expressed as a percentage of current volume are highest on State lands, followed by county and municipal, private, and finally Federal.

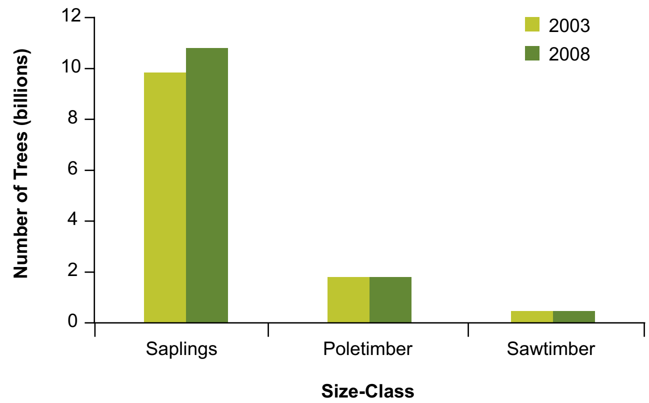

Figure 10.—Number of all live trees by size class on forest land, Minnesota, 2003 and 2008.

Number of Trees and Size Distribution

Background

An estimate of the number of trees in a forest is useful only when combined with information on diameter class distribution. Young forests have many more trees per acre than older forests, but older forests 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 13.1 billion trees on forest land. Of these trees, 82.7 percent are saplings (trees from 1 to 5 inches in diameter), 13.7 percent are poletimber-size trees (5 to 9 inches for softwoods and 5 to 11 inches for hardwoods), and 3.6 percent are sawtimber-size trees. Nearly two-thirds (64 percent) of the trees in Minnesota are hardwoods, and the rest are softwoods. Quaking aspen alone accounts for more than 26 percent of the total number of trees in Minnesota.

From 2003 to 2008, the total number of trees on forest land in Minnesota increased: saplings increased by 10 percent, sawtimber trees increased by 3 percent, and poletimber trees remained virtually the same (Fig. 10).

Although the number of poletimber trees remained nearly the same between the 2003 and 2008 inventories, the species composition changed significantly. Table 2 shows the species with the largest percent changes in numbers of poletimber trees.

Table 2.—Tree species with the largest increase/decrease in number of live poletimber-size trees and percent change between the 2003 and 2008 inventories (includes only species with more than 1 million trees in 2008)

Population Change	Species	Percent Change	2003 Millions of Trees	2008 Millions of Trees
Increase				
	Eastern redcedar	95.7	2.3	4.4
	Black walnut	54.0	1.1	1.7
	Bitternut hickory	52.9	1.2	1.9
	Silver maple	41.2	3.5	4.9
	Boxelder	37.7	16.6	22.8
	Green ash	27.0	28.0	35.5
	Black cherry	26.0	4.0	5.0
	American elm	22.2	29.0	35.5
	Eastern hophornbeam	18.8	10.6	12.6
	White spruce	10.5	22.3	24.7
	Red pine	9.8	52.6	57.7
Decrease				
	Northern red oak	-9.0	33.0	30.0
	Paper birch	-13.0	169.0	147.0
	Jack pine	-17.9	51.1	41.9
	Balsam poplar	-18.6	59.1	48.1
	White oak	-37.1	3.3	2.1

Between 2003 and 2008, the number of sawtimber-size trees increased slightly from 456 million to 471 million. While the number of sawtimber-size trees remained nearly the same, the species composition did not. In Minnesota, 33 tree species had more than one-half million sawtimber-size trees. Thirteen of these species had an increase of 20 percent or more in the number of trees from 2003 to 2008 (eastern redcedar, boxelder, American elm, red pine, green ash, eastern cottonwood, black walnut, white spruce, bur oak, silver maple, eastern white pine, black ash, and red maple). Six species (balsam poplar, white oak, jack pine, slippery elm, quaking aspen, paper birch) decreased by 10 percent or more in the number of sawtimber trees over the same 5-year period.

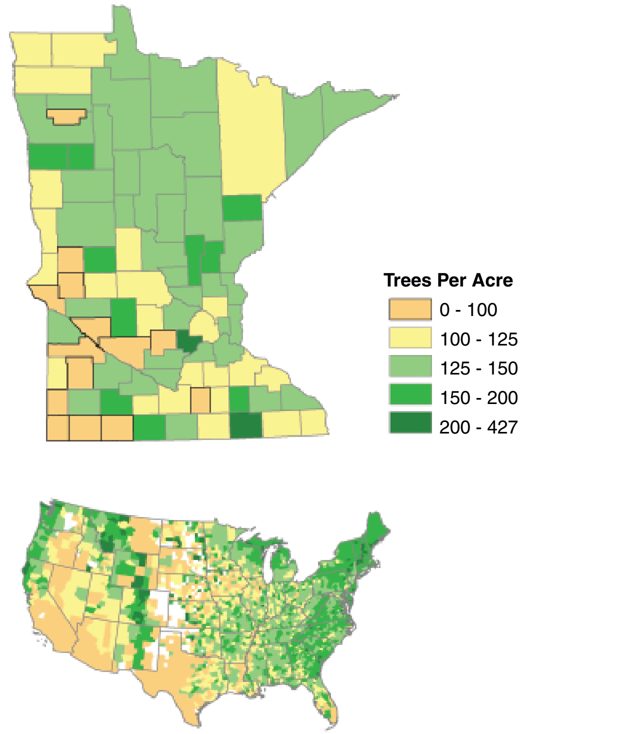

Figure 11.—Trees per acre of forest land, Minnesota and United States, 2008.

Basal area is the cross-sectional area of a tree 4.5 feet above the ground. If we were to measure the cross-sectional area of all the trees in a stand and then take the average, we would have the mean basal area per tree for the stand. It is easier to visualize tree diameter than mean basal area so 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 coterminous United States (Table 3). There are also fewer trees per acre than found in the rest of the country, partly because much of Minnesota lies in the transition zone between forest and prairie (Fig. 11). 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 (Fig. 12).

Table 3.—Minnesota in context: Average number of trees per acre and quadratic mean diameter

Geographic Area	QMD	Number of 5"+ Trees/acre of Forest Land	Number of 5"+ Trees/acre of Land
Conterminous United States	10.4	137.1	47.9
Lake States (MN, MI, WI)	9.2	152.2	57.2
Minnesota	8.9	133.0	41.9

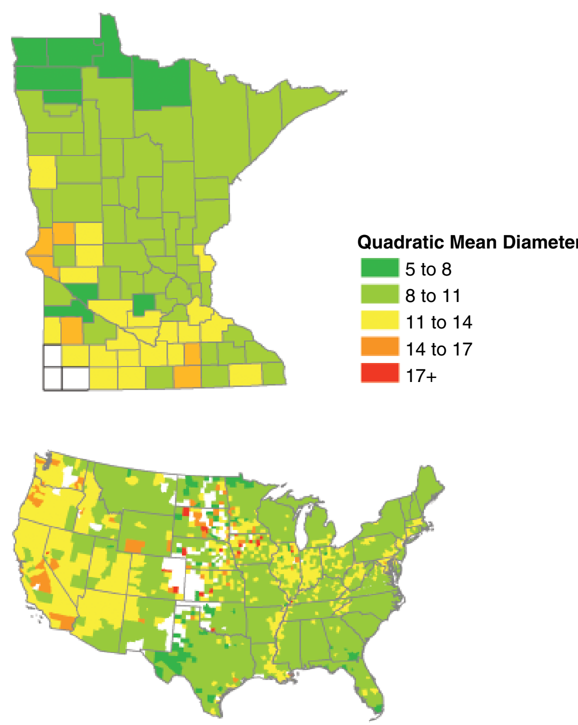

Figure 12.—Quadratic mean diameter (inches), Minnesota and United States, 2008.

What this means

In both 2003 and 2008, there were nearly 1.8 billion poletimber-size trees on forest land. Although the number of poletimber trees remained nearly the same between inventories, the species composition did not. The increase in eastern redcedar reflects the continued encroachment of this pioneer species on lands that had historically been prairie or farmland. The continued suppression of fire will result in a continued increase in eastern redcedar in the future. Increases in black walnut, bitternut hickory, and eastern hophornbeam may be at the expense of decreases in white and red oak. Oak regeneration is often made more difficult by the presence of shade-tolerant species. Increases in silver maple, box elder, green ash, black cherry, and American elm may reflect the increase in forest land in riparian areas and the conversion of windbreaks to forest land. Increases in the number of poletimber-size white spruce and red pine trees are the result of efforts conducted years ago because these two species make up nearly 80 percent of timberland artificially regenerated. 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 poletimber trees. Paper birch is susceptible to the bronze birch borer and Armillaria root disease. Recent droughts have also had an adverse impact on birch. The decline in balsam poplar is primarily due to aging as evidenced by the high proportion of large trees and an average annual mortality rate of 6.7 percent of the 2008 volume during the last inventory.

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 (includes stump, bole, and limbs but excludes foliage and roots) increases dramatically with increasing tree diameter (Table 4). Trees in the 7.0- to 8.9-inch class, for example, weigh slightly more than twice trees in the 5.0- to 6.9-inch class.

Table 4.—Average aboveground tree biomass in dry pounds by diameter class (inches) and major species group, Minnesota

Diameter Class	Softwoods	Hardwoods
1.0 - 2.9	5	7
3.0 - 4.9	30	46
5.0 - 6.9	92	130
7.0 - 8.9	192	271
9.0 - 10.9	329	458
11.0 - 12.9	500	696
13.0 - 14.9	720	985
15.0 - 16.9	1,016	1,341
17.0 - 18.9	1,372	1,790
19.0 - 20.9	1,829	2,215
21.0 - 28.9	2,875	3,453
29.0+	6,632	6,806

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 (in both years an average of 27 dry tons per acre of forest land). The distribution of forest biomass per acre of land is presented in Figure 13.

In 2008, 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 (Fig. 14). The boles of trees 5 inches d.b.h. and larger accounted for 64 percent of live-tree aboveground biomass, while their tops and limbs accounted for 16 percent and their stumps 4 percent. Nearly three-quarters of the total biomass was composed of hardwood species.

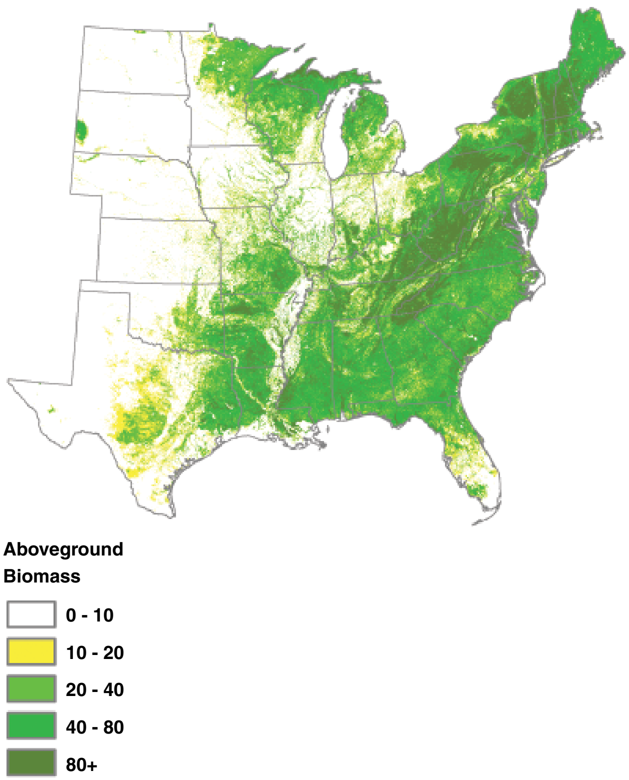

Figure 13.—Average all live-tree biomass in tons per acre of forest land, Eastern United States, 2008.

Table 5.—Minnesota in context: Biomass per acre of forest land

Geographic Area	Dry Tons Per Acre
Conterminous United States	39
Lake States (MN, MI, WI)	35
Minnesota	27

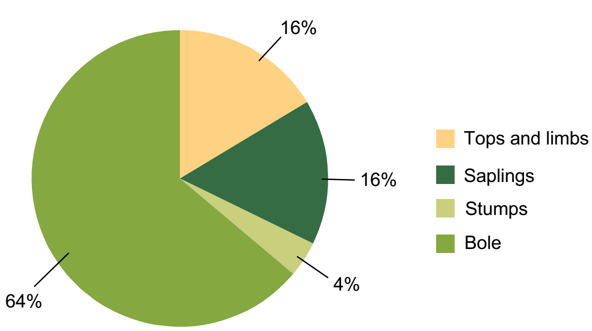

Figure 14.—Live-tree biomass by component on timberland, Minnesota, 2008.

The total live-tree aboveground dry biomass on timberland in 2008 was 428 million tons, a 5.4-percent increase from the 407 million tons reported in 2003 and a 24-percent increase from the 346 million tons reported in 1977 (Fig. 15).

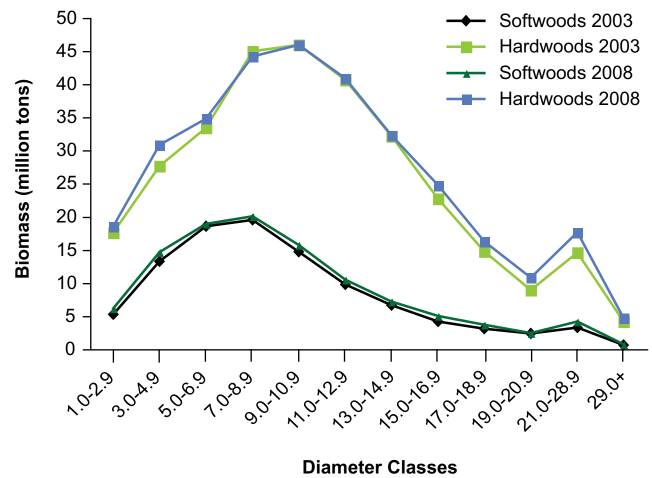

Figure 15.—All live aboveground dry biomass on timberland by major species group and 2-inch diameter classes, Minnesota, 2003 and 2008.

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.

Forest Carbon

Background

Interest in forest carbon has been growing as a result of increasing interest in global climate change and the role of forests in carbon storage. Forest ecosystems and forest products represent significant carbon sinks in the United States, equivalent in size to 10 percent of total U.S. greenhouse gas (GHG) emissions (U.S. EPA 2007).

In Minnesota, forest area is increasing while average biomass per acre is holding steady; therefore, forests in Minnesota currently remove more carbon from the atmosphere than they emit. FIA provides official forest greenhouse gas inventories of the United States (U.S. EPA 2008).

There are eight components of forest ecosystem carbon: (1) live-tree aboveground, (2) live-tree belowground, (3) understory vegetation aboveground, (4) understory vegetation belowground, (5) standing dead tree, (6) down dead wood, (7) forest floor litter, and (8) soil organic carbon. The live-tree aboveground carbon component is estimated directly from FIA data; the other carbon components are estimated using FIA data and coefficients from the FORCARB2 model (Birdsey and Heath 1995, 2001; Heath et al. 2003; Smith et al. 2004).

The method of estimating live-tree carbon was revised in 2009. Tree carbon estimates are now based on the component ratio method (CRM). CRM is based on (1) converting the sound volume of wood in the bole to biomass using a compiled set of wood specific gravities, (2) calculating the biomass of bark on the bole using a compiled set of percent bark and bark specific gravities, (3) estimating the stump, tops and limbs, and coarse roots as a proportion of the bole based on component proportions from Jenkins et al. (2003), and (4) summing the parts for total live biomass. This approach is based on assumptions that the definition of bole in the volume equations is equivalent to the definition of bole in Jenkins et al. (2003), and that the Jenkins et al. (2003) component ratios accurately apply (Heath et al. 2009). Carbon mass of wood is 50 percent of dry weight (IPCC 1997).

Understory vegetation is defined in FORCARB2 as all biomass of undergrowth plants in a forest, including woody shrubs and trees less than 1 inch in diameter, measured at breast height. Ten percent of understory carbon mass is assumed to be belowground. Model estimates are functions of condition-level forest type and live-tree carbon density.

Down dead wood is defined as pieces of dead wood greater than 7.5 cm diameter that are not attached to live or standing dead trees. Down dead wood includes stumps and roots of harvested trees. Model estimates are functions of condition-level forest type, stand age, and live-tree carbon density.

The standing dead tree component in FORCARB2 includes aboveground and belowground (coarse root) mass. Model estimates are functions of condition-level growing-stock volume of live trees, carbon density of live trees, forest type, and region.

Forest floor carbon is the pool of organic carbon (litter, duff, humus, and fine woody debris) above the mineral soil and includes woody fragments with diameters of up to 7.5 cm. Estimates are based on equations of Smith and Heath (2008) applied at the plot level. Forest floor and woody debris remaining after harvests are also included in calculating forest ecosystem carbon pools. Model estimates are functions of condition-level forest type and stand-age.

Estimates of soil organic carbon (SOC) are based on the national STATSGO spatial database and the general approach described by Amichev and Galbraith (2004). In their procedure, SOC was calculated for the coterminous United States using the STATSGO database, and data gaps were filled by representative values from similar soils. The SOC estimates are based on region and forest type only.

What we found

The amount of carbon on forest land increased by 4.5 percent from 2003 to 2008, from 1,665 million short tons to 1,740 million short tons (Fig. 16). Soil organic carbon is the largest component of forest carbon, followed by the aboveground carbon in trees and saplings, forest litter, tree and sapling roots, down and dead trees, standing dead and aboveground and belowground understory.

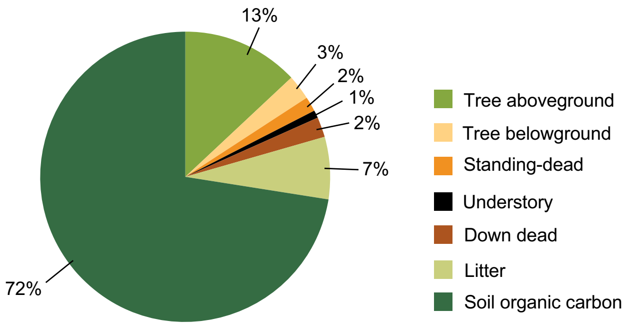

Figure 16.—Forest carbon by component, Minnesota, 2008.

What this means

The forests of Minnesota can help mitigate global climate change by serving both as a carbon sink and as a source of renewable bioenergy that can be used in place of nonrenewable fossil fuels.

Minnesota's forests have a large potential for carbon storage. The amount of live-tree carbon stored on Minnesota's timberland has increased by 24 percent over the past 33 years and by more than 5 percent in the last 5 years. Forest management for carbon credit trading could become a viable economic alternative to other management options (e.g., harvesting) given established carbon markets. Managing forest carbon stocks is not as simple as maximizing live-tree growth due to the importance of other carbon stocks such as soil organic components and belowground carbon stocks. Management impacts on non-live-tree carbon stocks need to be identified.

There are limits to the amount of carbon that can be stored in a forest. At some point mortality will equal or exceed growth and the forest will actually release carbon rather than sequester it. As a renewable energy source, biomass is a sustainable carbon-neutral feedstock if managed properly (Schlamadinger et al. 1995, Schwaiger and Schlamadinger 1998). Carbon assessments are becoming increasingly important as public concern over climate change grows. Future FIA reports may include estimates of the amount of fossil fuels supplanted by the use of woody biomass for bioenergy.

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 16.3 billion in 2003 to 16.8 billion in 2008 (Table 6). Historically, over 13 percent of live-tree volume falls in the rough and rotten cull category. This was true in both the 1977 and 2008 inventories. The cull proportion reported in 2003, however, was only half this rate. Rough and rotten cull volume went from 13.6 percent of live volume in 1977 to 6.5 percent in 2003 to 13.8 percent in 2008. If we adjust the 2003 cull proportion to reflect historic levels, growing-stock volume would have increased from 12.3 billion cubic feet in 1977 to 14.1 billion in 2003 to 14.5 billion in 2008 while rough and rotten cull would have increased from 1.9 billion in 1977 to 2.2 billion in 2003 to 2.3 billion in 2008.

Table 6.—Live-tree volume (million cubic feet) on timberland by tree class, Minnesota, 1977, 2003, and 2008

Tree Class	1977	2003	2008
Growing stock	12,350	15,243	14,525
Rough and rotten cull	1,949	1,064	2,320
Total	14,299	16,307	16,845

Figure 17 shows the change in all live volume on timberland by species for the 12 species having the largest volume in 2008 (76 percent of the total). Between 2003 and 2008, there were winners and losers. The big winners included red pine, which increased in volume by 25 percent, bur oak (18 percent), American basswood (9 percent), northern white-cedar (9 percent), and northern red oak (8 percent). The losers included paper birch with a 10-percent decline, quaking aspen (-7 percent), and balsam fir (-3 percent).

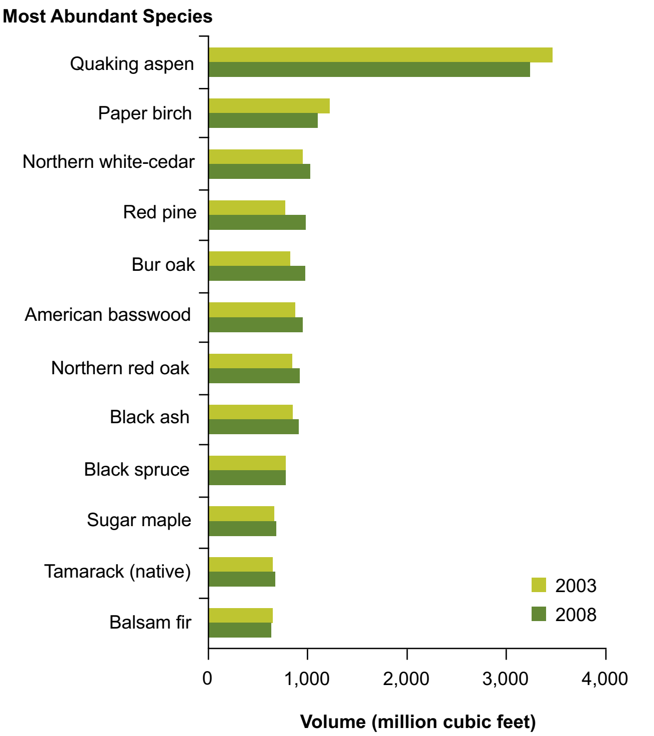

Figure 17.—All live volume by species on timberland, Minnesota, 2003 and 2008.

The aspen resource is concentrated in northeastern Minnesota. The decrease in growing-stock volume of aspen from 2003 to 2008 was due primarily to high levels of removals. All live volume on timberland decreased by 7 percent, from 3.5 billion cubic feet in 2003 to 3.2 billion cubic feet in 2008. The volume of aspen is expected to increase over the next inventory as a large area of 10- to 20-year-old aspen grows into poletimber-size timber.

The area of timberland increased by 5.9 percent from 2003 to 2008. This new timberland was sparsely treed, resulting in a decline in the overall volume per acre on timberland from 1,107 cubic feet in 2003 to 1,079 cubic feet in 2008.

Volume on forest land

Ninety-eight percent of all live-tree volume on forest land (18.1 billion cubic feet) comes from just 26 of the 71 species measured during the 2008 inventory. Leading the list is quaking aspen at 19 percent, followed by paper birch at 7 percent, northern white-cedar at 6 percent, and red pine at 6 percent (Figs. 18, 19).

Most softwoods are located in north-central and northeastern Minnesota (Fig. 20).

What this means

Aspen volumes are near historic levels although there has been a moderate decline as a result of current demand. In the short term, aspen volumes are expected to increase as large areas of regenerated aspen grow into poletimber. Demand for aspen and other species will increase as demand for bioenergy increases.

Most other species have had increasing volumes, except for balsam fir and paper birch (which had very high rates of mortality). Removals rates for these species are significantly lower than those for aspen.

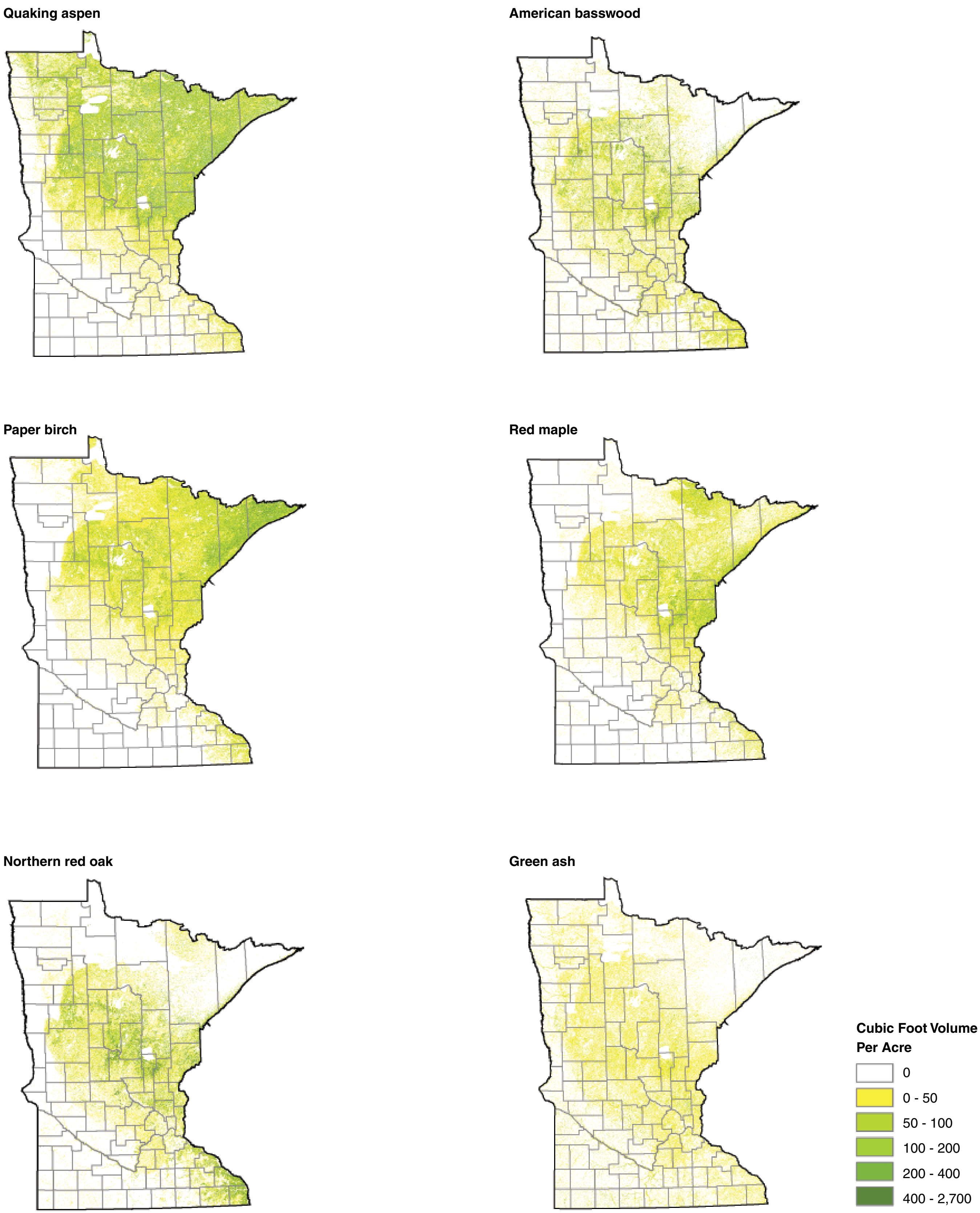

Figure 18.—All live-tree volume (in cubic feet per acre) on forest land for selected hardwood species, Minnesota, 2008.

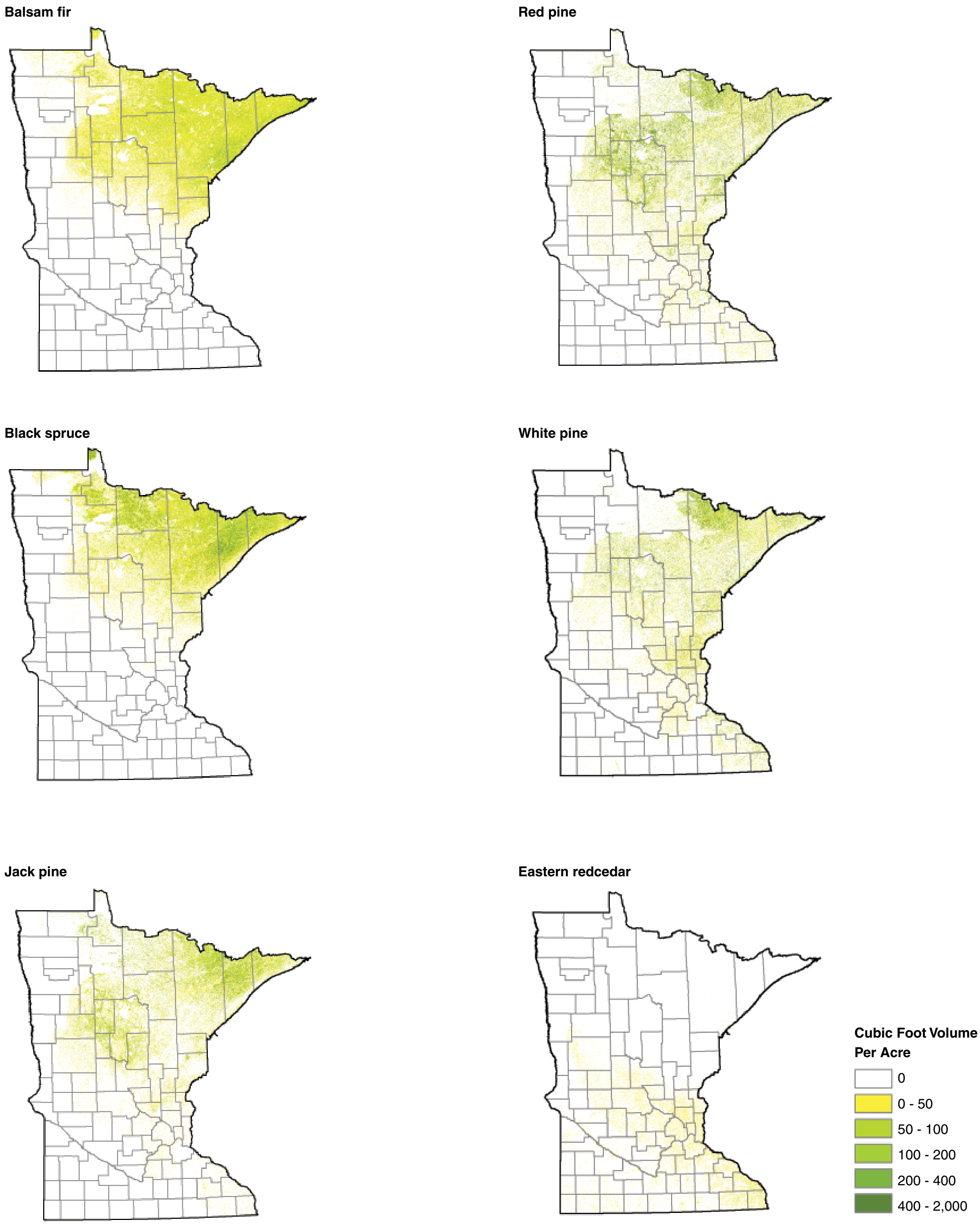

Figure 19.—All live-tree volume (in cubic feet per acre) on forest land for selected softwood species, Minnesota, 2008.

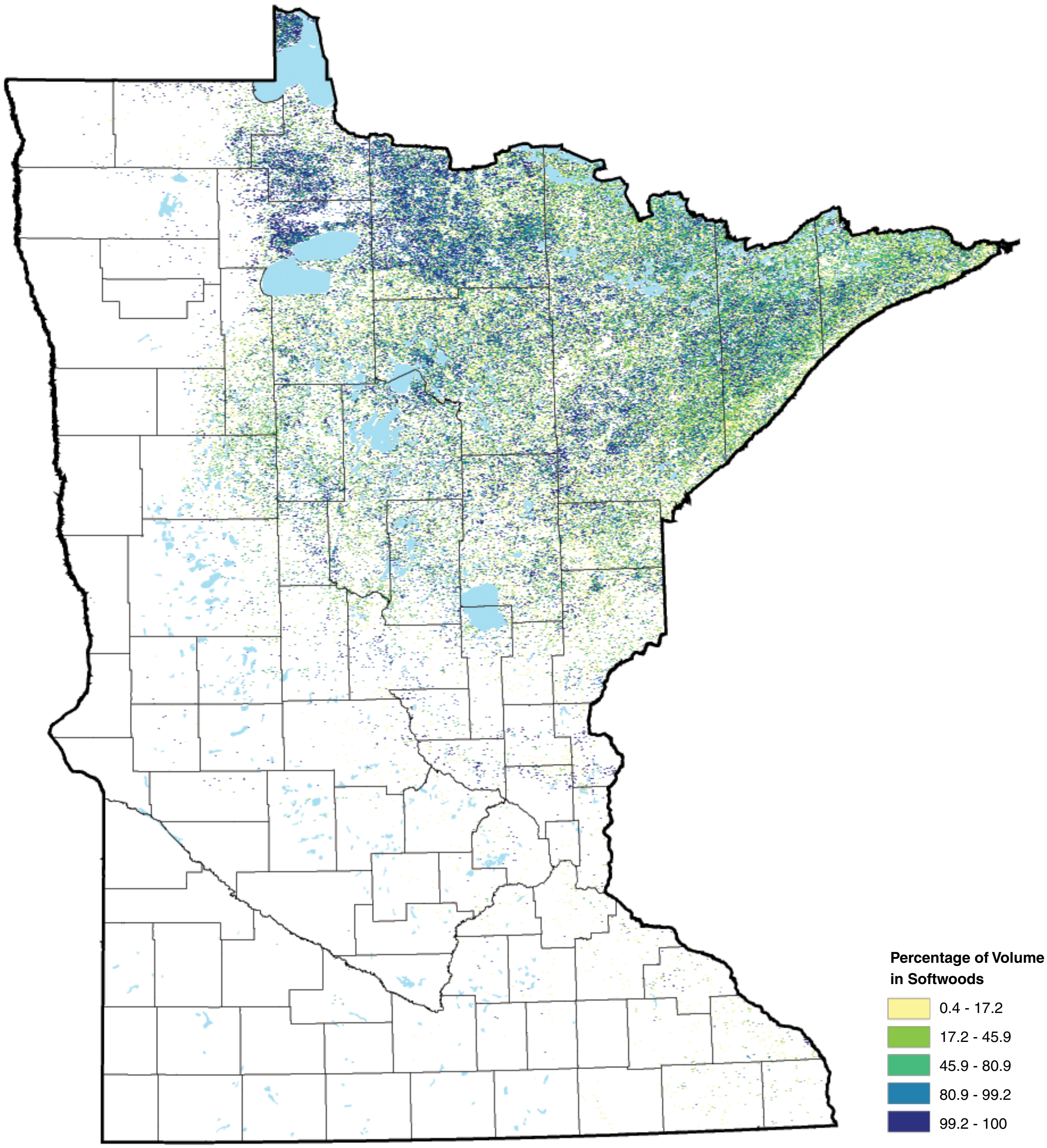

Figure 20.—Percent of all live volume in softwood species, Minnesota, 2008.

Sawtimber Volume and Quality

Background

A board foot is a unit of measure 1 inch by 1 inch by 12 inches. Tree grade 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 4.

Softwood sawtimber is primarily valued for dimensional lumber, while hardwood sawtimber is valued for use in flooring and furniture. Softwood trees must be at least 9 inches in d.b.h. to qualify as sawtimber-size trees under the FIA definition; hardwoods must be at least 11 inches in d.b.h.

What we found

Sawtimber volume on forest land totaled 40.2 billion board feet in 2008. This is down from the 42.2 billion board feet reported in 2003. This decline was the result of an apparent misinterpretation of field procedures during the 2003 inventory resulting in total cull representing only 6.5 percent of all live volume – well below historic levels (Fig 21). The problem was rectified in the 2008 inventory where the total cull rate of 13.8 percent was much closer to historic levels. The cull rate for softwoods went from 2.4 percent in 2003 to 5.1 percent in 2008. The cull rate for hardwoods went from 8.3 percent in 2003 to 17.6 percent in 2008. If we assume the cull rate was unchanged over the period, we would expect to see a total sawtimber volume in 2003 of approximately 39.1 billion board feet.

If we assume identical cull rates for the 2003 and 2008 inventories, the volume of sawtimber on timberland would have increased over the period (Fig. 22). The increase in softwood sawtimber is greater than the decrease in hardwood sawtimber volume.

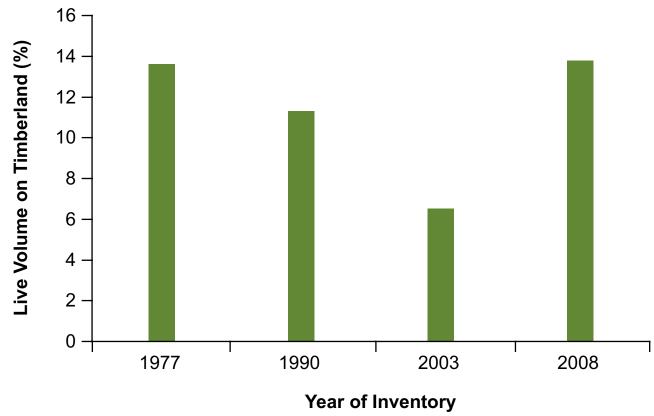

Figure 21.—Percent of all live volume on timberland that is cull by inventory year, Minnesota.

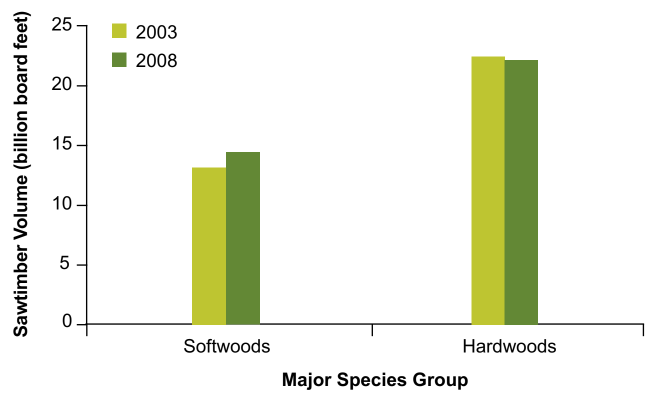

Figure 22.—Sawtimber volume on timberland by major species group and inventory year, Minnesota. Note: 2003 sawtimber volumes used to create this figure were adjusted downward because the percent of all live volume called cull in 2003 was only about half that of previous and successive inventories.

Of the 73 tree species measured on FIA plots during the 2008 inventory, 44 had attained sawtimber size. Seventy-two percent of the sawtimber volume on timberland was found in just 10 species (Fig. 23). The volume in each of these species, except for quaking aspen and paper birch, increased from 1977 to 2003. Since 2003, sawtimber volume has been leveling off or decreasing for these species except for red and white pine.

The majority of sawtimber is in tree grade 3 for both hardwoods (41 percent) and softwoods (56 percent) (Fig. 24). Tree grade 2 represents 30 percent of total hardwood volume and 11 percent of softwood volume. Grade 1 constitutes 11 percent and 26 percent of hardwood and softwood volumes, respectively.

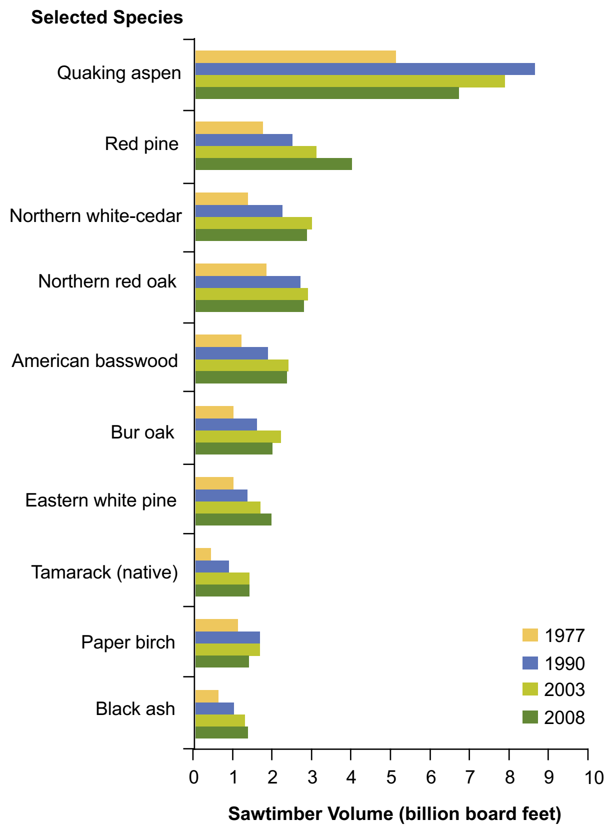

Figure 23.—Sawtimber volume (billion board feet) on timberland by selected species, Minnesota, 1977, 1990, 2003, 2008.

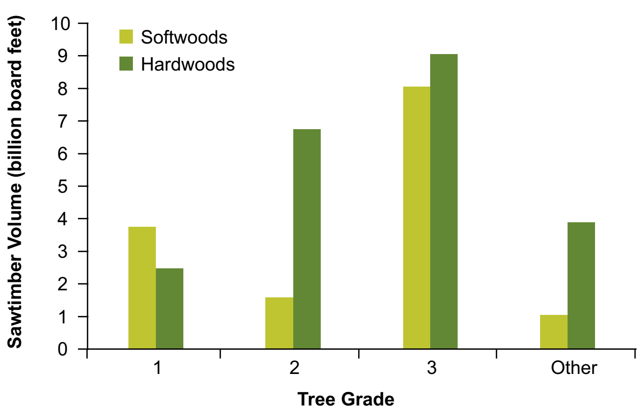

Figure 24.—Sawtimber volume (billion board feet) on timberland by major species group and tree grade, Minnesota, 2008.

What this means

The volume of sawtimber is decreasing for pioneer species like quaking aspen, paper birch, and jack pine and for species that have had high rates of mortality such as balsam fir, American elm, and butternut. 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 land (3,125 board feet), followed by privately owned land (2,449 board feet), and finally state and local government land (1,975 board feet). This reflects the removals levels of live trees on timberland for each of the ownership groups. Removals as a percent of standing volume is lowest for Federal ownership (0.7 percent), followed by private ownership (1.6 percent), and finally state and local government ownership (2.6 percent).

Stocking and Stand-size Class

Background

Stocking provides information on the degree of occupancy of land 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

Just over half (52 percent) of the forest land in Minnesota is fully stocked or overstocked, 33 percent is medium stocked, and 15 percent is poorly stocked or nonstocked. There is no discernible pattern to the spatial distribution of stocking in the State. The proportion of seedling-sapling stands that are overstocked or fully stocked is 69 percent, followed by large-diameter stands (49 percent) and medium-diameter stands (39 percent).

Stocking levels vary by forest type (Fig. 25). Aspen forest land is nearly 66 percent fully or overstocked, while tamarack is only 33 percent fully stocked or overstocked. Stocking is generally lower on low-lying forest types.

proportion of land area in each of the stand-size classes varies considerably by forest type (Fig. 26). More than 65 percent of the hard maple/basswood forest 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 class.

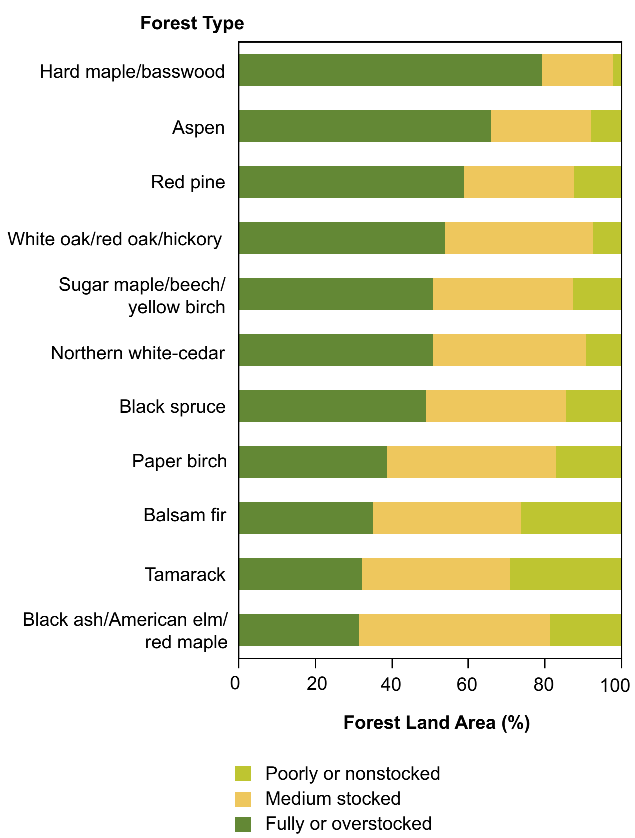

Figure 25.—Proportion of forest land area by stocking class for each forest type, Minnesota, 2008.

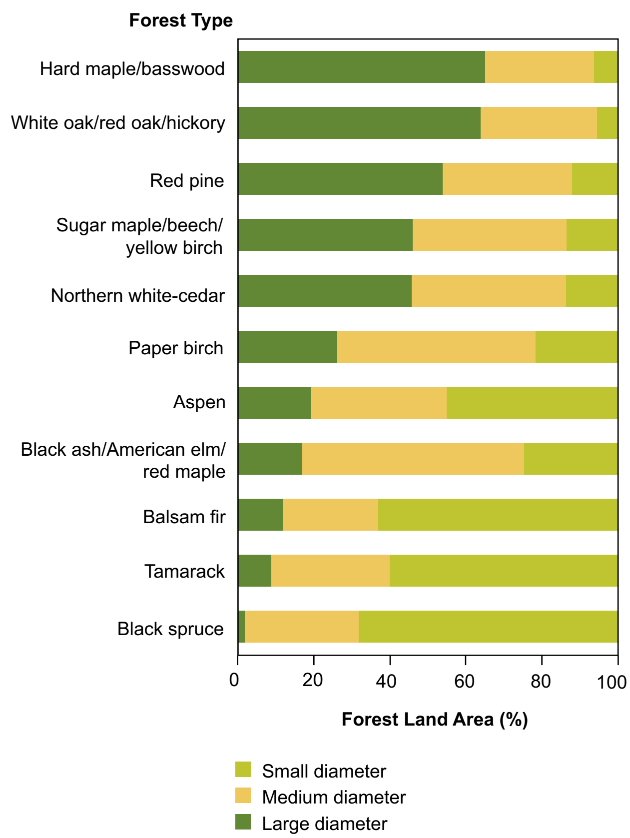

Figure 26.—Proportion of forest land area by stand-size class for each forest type, Minnesota, 2008.

The forests of Minnesota are fairly evenly split between three stand-size classes. Large-diameter stands (where a plurality of stocking is in hardwoods 11 inches d.b.h. and larger and softwoods 9 inches d.b.h. and larger) are found on 29 percent of Minnesota's 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 from 5 to 9 inches and hardwood trees from 5 to 11 inches, occupy 35 percent of the forest land in Minnesota. The

All live basal area per acre of timberland was 84 square feet per acre in 2008, a significant increase over the 79 square feet per acre in 2003 and the 78 square feet per acre in 1977.

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's forests, active management of woodlots to promote 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 type in small-diameter stands, which also points to regeneration problems. Regeneration in northern white-cedar is often hindered by browsing.

Tree Growth

Background

Growth is computed by measuring trees at two points in time and determining the average annual change in volume over the period. If the volume on a plot increased from 2003 to 2008, then a net increase in growth would be reported. If the volume declined due to mortality, then there would be a net decrease in growth. The total volume change divided by the number of years between measurements would yield the net average annual growth on the plot.

What we found

The average annual net growth of live trees on forest land from 2003 to 2008 was 435 million cubic feet or roughly 2.4 percent of the total live-tree volume in 2008. Growth expressed as a percent of volume is presented for the 12 most abundant species (by cubic foot volume) in Minnesota in 2008 (Fig. 27). The growth rate for red pine was the greatest at 4.6 percent; the growth rate for paper birch was only 0.1 percent due to excessive mortality rates.

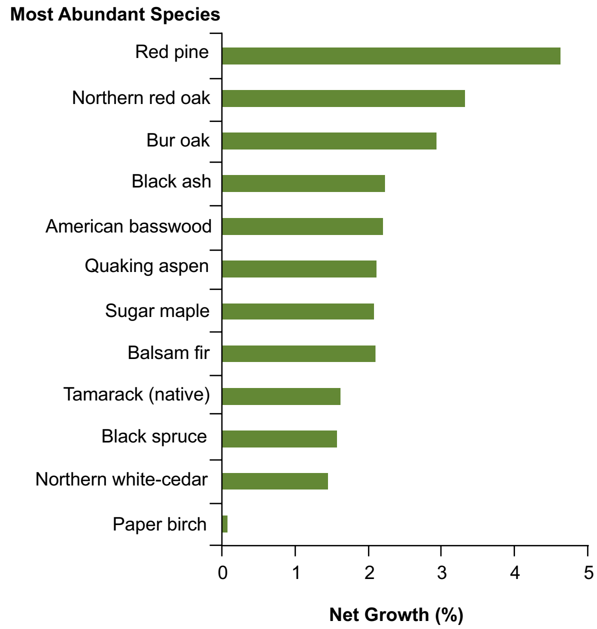

Figure 27.—Average annual net growth of live trees on forest land as a percent of volume for 12 most abundant species in Minnesota, 2008.

The average annual net growth rate of live trees on forest land as a percent of volume varies by landowner class. The rate is highest for private landowners (3.2 percent) followed by state and local governments (2.1 percent), other Federal (1.6 percent), and finally national forests (1.0 percent). The spatial distribution of growth is presented in Figure 28. In this graphic, counties were used to plot the growth rate of live trees on forest land. Counties with low average annual net growth rates (less than 1 percent of growing-stock volume) are shaded green. Counties with moderate growth (1 to 2 percent) are shaded yellow. High growth is shaded orange (2 to 3 percent) and very high growth is shaded red. 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.

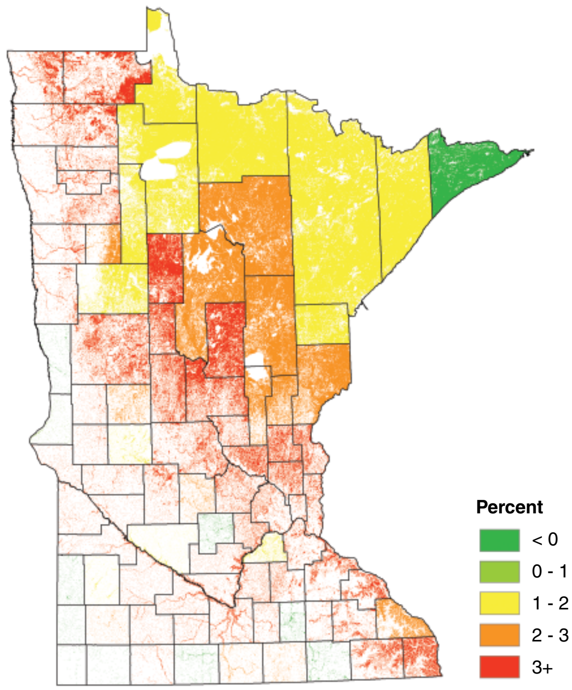

Figure 28.—Average annual net growth of live trees on forest land as a percent of live-tree volume on forest land, Minnesota, 2008.

What this means

Growth rates are useful indicators of sustainability, disturbance trends, species 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 greater than 5 inches in diameter. As a result, information on the understory component is not reflected in any of these measures.

Tree 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 2008 was 340 million cubic feet or roughly 1.9 percent of the 2008 volume. Mortality expressed as a percent of volume is presented for the 12 most abundant (by cubic foot volume) species in Minnesota in 2003 (Fig. 29). The mortality rate for balsam fir was the highest at 4.6 percent; the mortality rate for red pine the lowest at 0.3 percent.

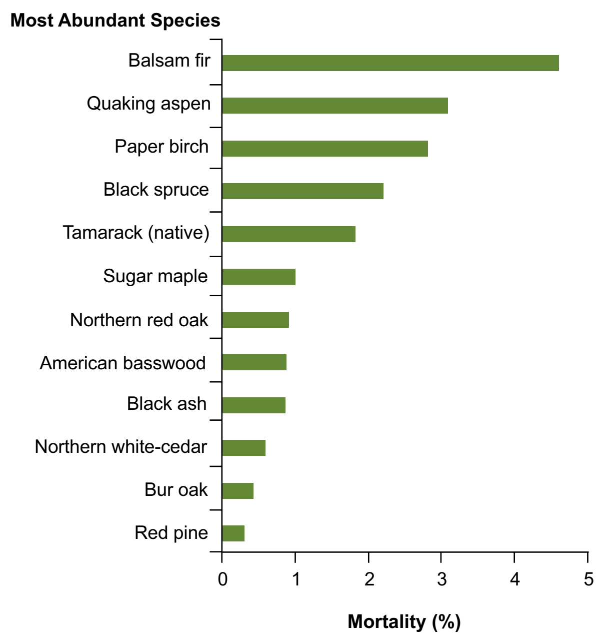

Figure 29.—Average annual live-tree mortality on forest land as a percent of volume for the 12 most abundant species in Minnesota, 2008.

The primary cause of mortality could not be determined in 43 percent of the cases. This is not surprising considering that the trees are revisited only every 5 years so a tree could have been dead for up to 5 years when revisited by the field crews.

Among the various identifiable primary causes of tree mortality were weather (41 percent), disease (37 percent), insect (8 percent), animal (5 percent), fire (5 percent), and other vegetation (4 percent). Although insects were responsible for only a small percentage of the primary cause of mortality, they contributed to a much greater share of it by weakening trees and making them vulnerable to disease and other forms of attack.

The average annual mortality of live trees on forest land reported in 2008 expressed as a percentage of the 2008 volume is 1.9 percent. The average annual mortality of growing-stock trees on timberland is slightly lower at 1.7 percent of the growing-stock volume on timberland. This is significantly higher than the rate reported for the 1977 inventory (1.2 percent) or for the 1990 inventory (1.3 percent). The rate of 1.7 percent is also significantly higher than the mortality rates for neighboring states, Iowa (1.2 percent) and Wisconsin (1.0 percent).

The mortality rate of live trees on forest land as a percent of current live-tree volume varies by landowner class. The rate is highest for national forests (2.3 percent) followed by state and local governments (1.9 percent) and private land owners (1.7 percent). The spatial distribution of mortality is presented in Figure 30. A nonforest mask was placed over the counties to more fairly represent the forest area on which mortality would have occurred.

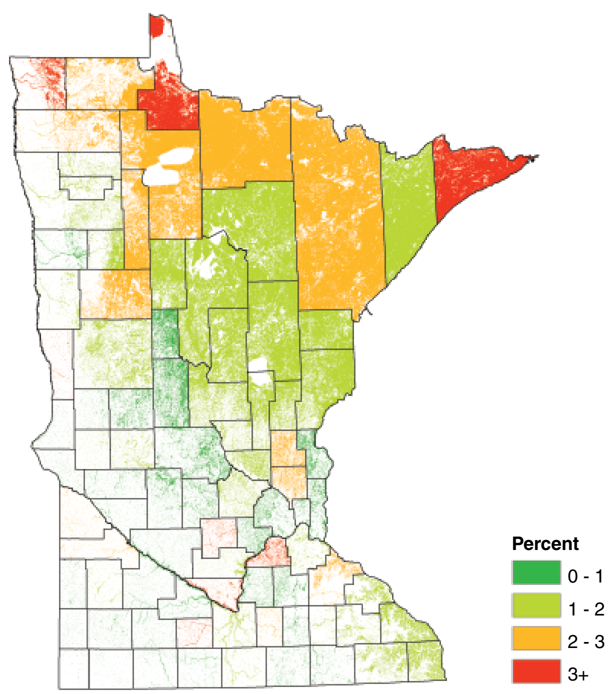

Figure 30.—Average annual live-tree mortality on forest land as a percent of live-tree volume on forest land, Minnesota, 2008.

What this means

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

Tree Removals

Background

There are three types of removals: harvest removals, mortality removals – trees killed during the harvesting process and left on the land, and diversion removals – living trees previously on land classified as forest land now on land classified as nonforest land (removed from the forest land base due to land use change).

What we found

The average annual live-tree removals on forest land for Minnesota in 2008 was 288 million cubic feet or roughly 1.6 percent of the total tree volume in 2008. Removals expressed as a percent of volume is presented for the 12 most abundant (by volume) species in Minnesota in 2008 (Fig. 31). The removals rate for quaking aspen was the greatest at 3.4 percent while the removals rate for northern white-cedar was the lowest at 0.0 percent.

The removals rate as a percent of volume varies by landowner class. The rate is highest for state and local governments (2.2 percent) followed by private land owners (1.5 percent), other Federal (0.7 percent), and finally national forests (0.4 percent). The spatial distribution of removals is presented in Figure 32. 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.

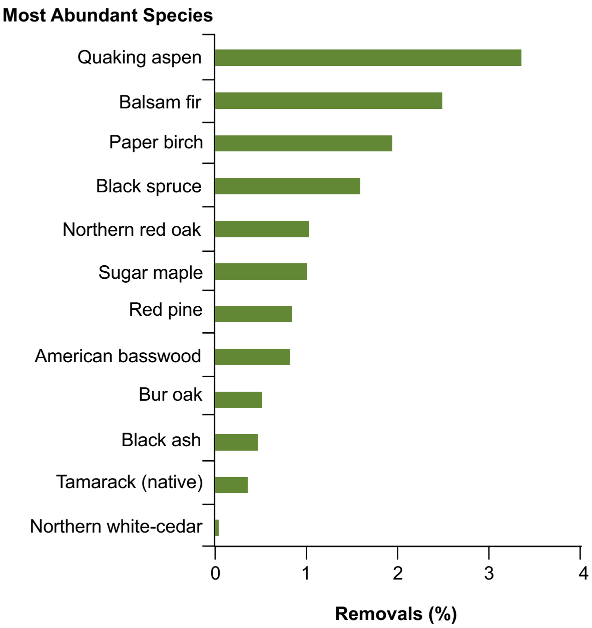

Figure 31.—Average annual removals of live trees on forest land as a percent of volume for 12 most abundant species in Minnesota, 2008.

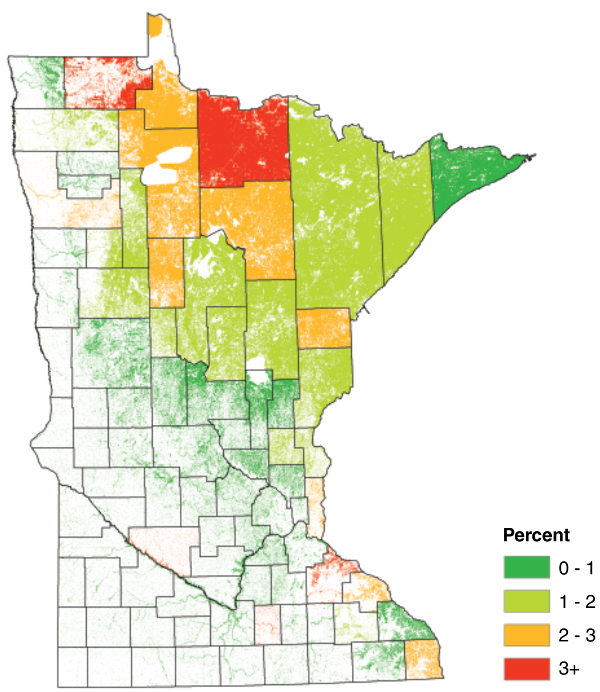

Figure 32.—Average annual live-tree removals on forest land as a percent of live-tree volume on forest land, Minnesota, 2008.

Most (97 percent) of the removals of live trees from forest land in Minnesota over the period, as measured from FIA field plots, were due to harvesting. Eighty-nine percent of the removals were cut and utilized; 8 percent were killed as a result of the harvesting process and left in the forest (Fig. 33). The remaining 3 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.

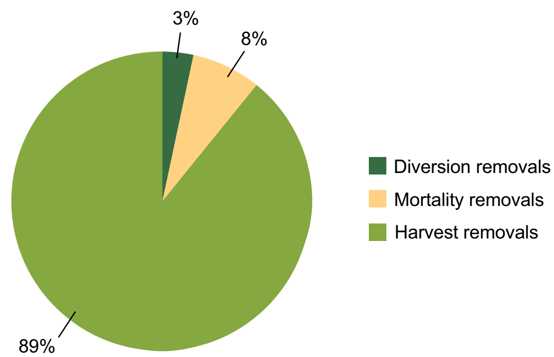

Figure 33.—Average annual growing-stock removals from forest land by disposition of timber, Minnesota, 2008.

What this means

Landowner objectives have a large impact on removal rates. On average, in Minnesota, state and county lands are more actively managed than other 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.

Growth-to-Removals Ratio

Background

One measure of sustainability is the growth-to-removals ratio (G/R). The growth-to-removals ratio is simply the net growth divided by removals where net growth is equal to gross growth minus mortality. A number greater than 1.0 indicates that the volume of the species is increasing. A number less than 1 indicates that the volume is decreasing.

What we found

Overall, the growth-to-removals ratio of live trees on forest land for 2003 to 2008 was 1.5, indicating that overall volume is indeed increasing. By ownership class, the growth- to-removals rates are 2.5 for the national forests, 2.2 for other Federal ownership, 2.0 for private ownership, 1.0 for county and municipal, and 0.8 for State-administered lands. On a species-by-species basis, the picture is less clear (Table 7). Northern white-cedar has a G/R ratio of over 45; paper birch has a G/R ratio of nearly zero because mortality nearly matches gross growth, resulting in a very small net growth.

The average annual removals of growing-stock trees on timberland reported for 2004 to 2008 (294 million cubic feet) was higher than the 249 million cubic feet reported for 1999 to 2003. Harvest removals of growing stock on timberland was estimated at 235 million cubic feet in 2008, an increase of 32 percent over the 178 million cubic feet of harvest removals for the period ending in 2003. 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 very small G/R because its mortality nearly matched gross growth over the period. High mortality rates for balsam fir due to spruce budworm infestations were partially responsible for a low G/R.

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

Table 7.—Ratio of average annual net growth of live trees on forest land to average annual removals of live trees on forest land for the 12 most abundant species in Minnesota, 2008

Species	Growth/ Removals	Net Growth of All Live Trees on Forest Land (thousand ft^3)	Removals of Live Trees on Forest Land (thousand ft^3)	Volume of Live Trees on Forest Land (thousand ft^3)
Northern white-cedar	45.45	15,549	342	1,074,916
Bur oak	5.80	29,585	5,105	1,008,012
Red pine	5.52	47,315	8,565	1,022,939
Black ash	4.86	21,568	4,441	967,514
Tamarack (native)	4.61	11,206	2,429	690,116
Northern red oak	3.24	31,900	9,853	959,141
American basswood	2.71	21,353	7,880	967,607
Sugar maple	2.08	14,291	6,870	688,044
Black spruce	0.99	13,808	13,940	881,947
Balsam fir	0.84	14,070	16,707	672,489
Quaking aspen	0.63	72,922	116,154	3,464,423
Paper birch	0.04	915	23,796	1,225,827

Health Indicators

Thistledew Campground, Dorothy Becher.

Crown Conditions

Background

The overall condition of tree crowns within a forest stand may indicate the health status of forests. For example, a forest suffering from a disease epidemic will have low crown ratios, high transparency, and obvious dieback.

What we found

Dieback is measured as the percent of dead branch tips in the crown. The categories for the dieback indicator are none (1-5 percent), light (6-20 percent), moderate (21-50 percent), and severe (51-100 percent). Overall, 87 percent of the trees had no dieback, 10 percent had light, 2 percent had moderate, and only 1 percent had severe (Fig. 34). The ash species group is the most susceptible to dieback (Fig. 35); 14 percent of the trees had light dieback and 6 percent had moderate to severe dieback in the 2008 inventory.

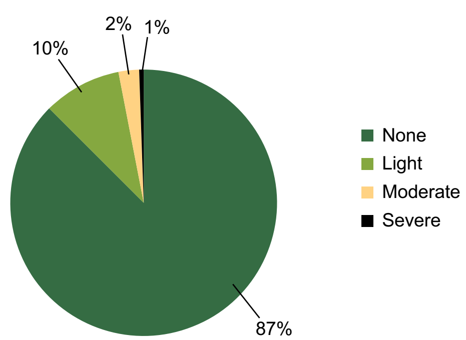

Figure 34.—Dieback class of all species, Minnesota, 2008.

In Minnesota, where the emerald ash borer (EAB) has only recently been discovered, 20 percent of the ash trees have dieback. In Michigan, where the EAB is widespread, 23 percent of the ash trees have dieback. These similar dieback rates are probably due to the short window between EAB infestation and tree mortality. Dieback is measured only on live trees.

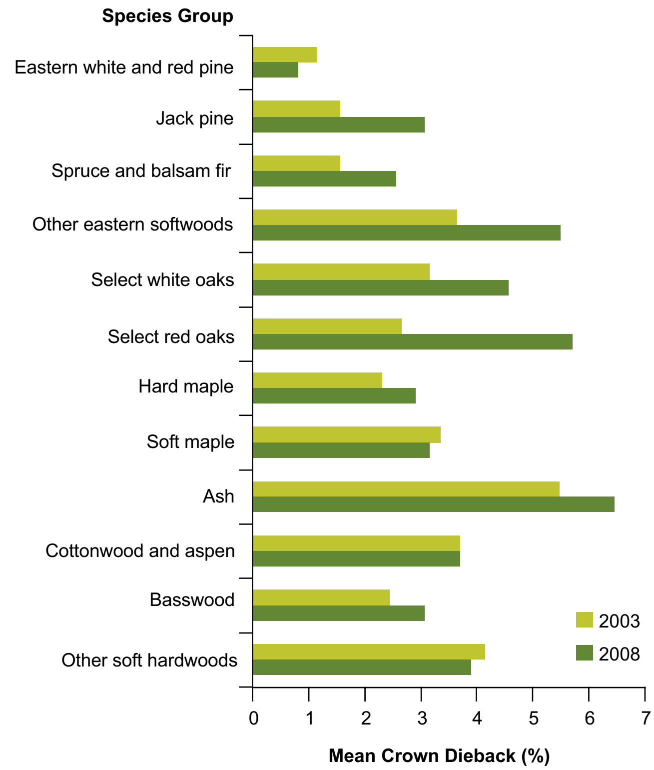

Figure 35.—Mean crown dieback in percent by species group, Minnesota, 2003 and 2008.

The crown ratio of a tree is defined as the portion of the tree height supporting live foliage. The spruce and balsam fir species group has the highest mean crown ratio at 70 percent (Fig. 36). The cottonwood and aspen species group has the lowest mean crown ratio at 40 percent.

Crown transparency is a measure of the proportion of the crown through which the sky is visible. The ash species group had the highest average crown transparency at 23 percent; the spruce and fir species group had an average crown transparency of only 16 percent (Fig. 37).

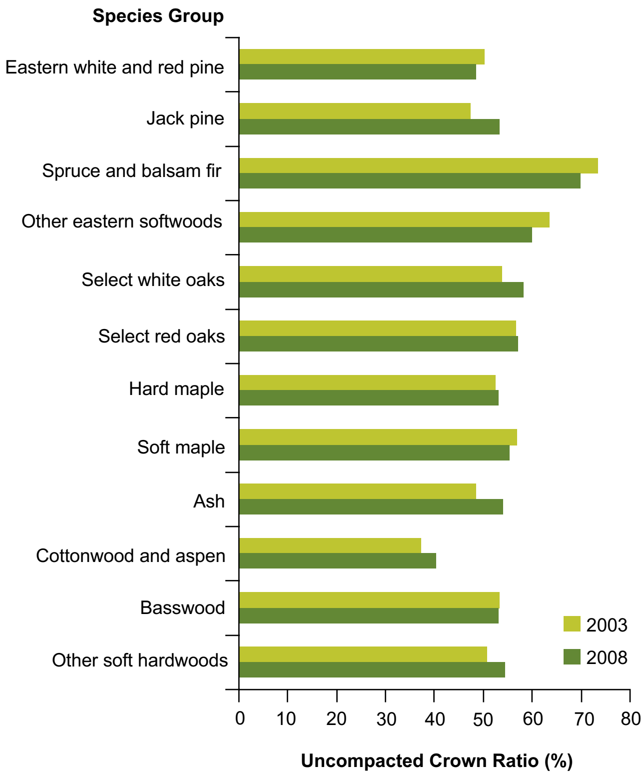

Figure 36.—Uncompacted crown ratio in percent, Minnesota, 2003 and 2008.

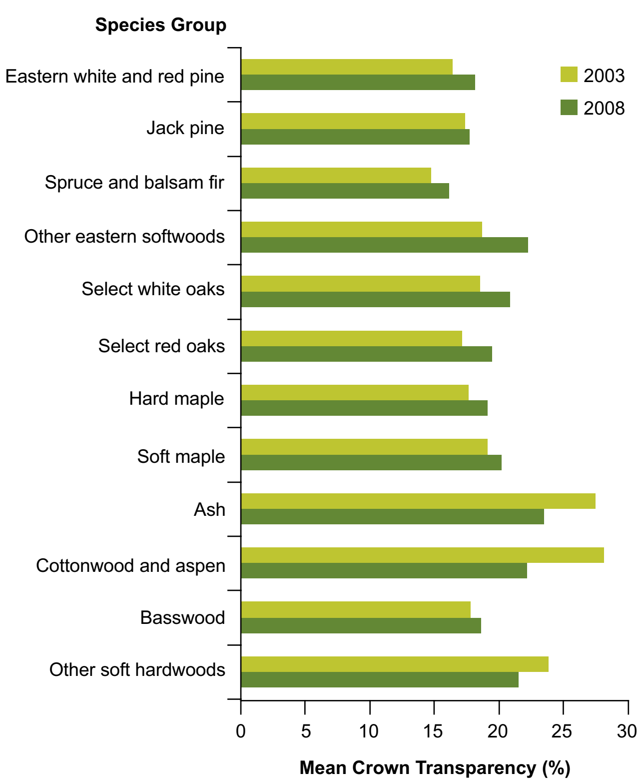

Figure 37.—Mean crown transparency in percent by species group, Minnesota, 2003 and 2008.

What this means

Because crown conditions were sampled on a small subset of forest inventory plots (184 forested phase 3 forest health plots) it is not appropriate to calculate population estimates. However, means of the crown indicators by species group appear to indicate there are no major health problems with crown conditions in Minnesota. Trend data are needed to develop a baseline for crown health. Crown ratio and crown transparency appear to be inversely related – the higher the crown ratio the lower the transparency. Crown ratios are generally higher for wolf trees and trees on the edge of the forest. Increased forest fragmentation may therefore result in higher average crown ratios.

Down Woody Materials

Background

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

What we found

The fuel loadings of down woody materials (time-lag fuel classes) are not exceedingly high in Minnesota (Fig. 38). When compared to nearby Michigan and Wisconsin with similar forest ecosystems, Minnesota's fuel loadings of all time-lag fuel classes are not substantially different (for time-lag definitions, see Woodall and Monleon 2008). The size-class distribution of coarse woody debris by number of pieces appears to be heavily skewed (79 percent) toward pieces less than 8 inches in diameter at point of intersection with plot sampling transects (Fig. 39). In the decay class distribution of coarse woody debris, there appears to be moderate stages of coarse woody decay across the State (decay classes 2, 3, and 4; totaling 87 percent) (Fig. 40). Coarse woody pieces in decay class three and four are typified by moderate to heavily decayed logs that are sometimes structurally sound but missing most/all of their bark with extensive sapwood decay. There is no strong trend in coarse woody debris volumes/acre among classes of live-tree density (basal area/acre). Most of Minnesota's forests appear to have more than 400 cubic feet of coarse woody debris volume/acre (Fig. 41).

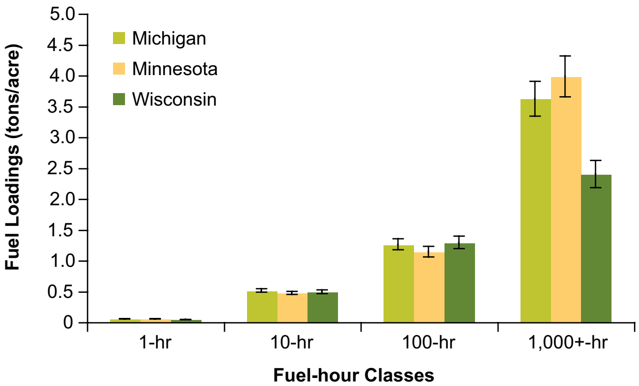

Figure 38.—Means and associated standard errors of fuel loadings (tons/acre, time-lag fuel classes) on forest land in Minnesota and nearby states, 2008.

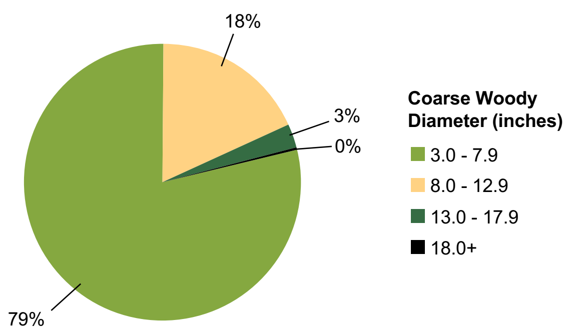

Figure 39.—Mean proportions of total pieces of coarse woody debris per acre by transect diameter (inches) on forest land in Minnesota, 2008.

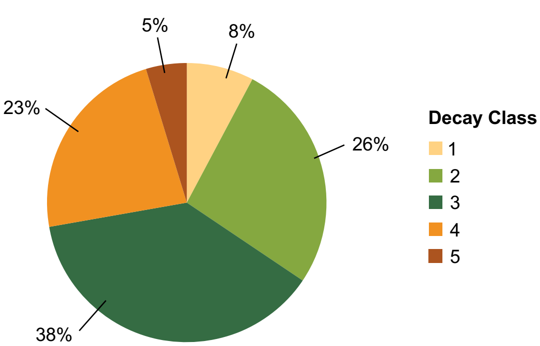

Figure 40.—Mean proportions of total pieces of coarse woody debris per acre by decay classes on forest land in Minnesota, 2008.

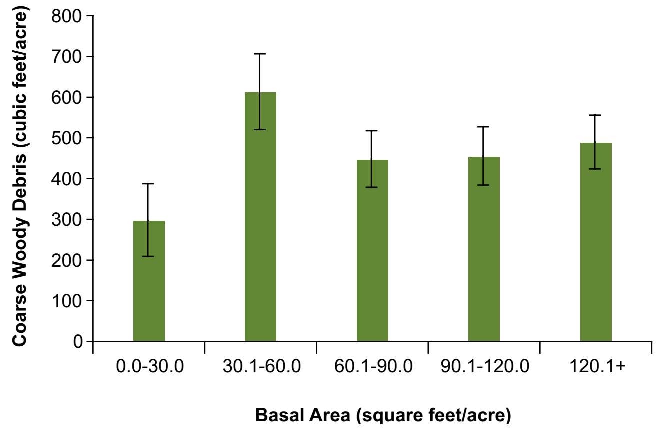

Figure 41.—Means and associated standard errors of coarse woody debris volumes (cubic feet/acre) by live-tree basal area class on forest land in Minnesota, 2008.

What this means

The down woody fuel loadings in Minnesota's forests are not very different from those found in nearby states. Therefore, only in times of extreme drought would these fuel loadings pose a hazard across the State. Of all down woody components, coarse woody debris (i.e., 1,000+-hr fuels) made up the largest amounts. However, coarse woody debris volumes were still relatively low and were represented by small, moderately decayed pieces. The scarcity of large coarse woody debris resources may also indicate a lack of high quality wildlife habitat. Overall, because fuel loadings are not very high across Minnesota, possible fire dangers may be outweighed by the down woody material benefits of wildlife habitat and carbon sinks.

Forest Insects and Pathogens

Background

Minnesota's forests sustained damage from a combination of abiotic stressors and native and nonnative pests in the period from 2004 to 2008. Many of the native pests are recurring and cyclic, and they play an integral role in the ecology of Minnesota forests. The early detection and treatment of gypsy moth outbreaks and the emerald ash borer has slowed the introduction and spread of these two destructive insects.

Historically, exotic insects and pathogens have had a large impact on Minnesota's forest health. Diseases such as white pine blister rust (*Cronartium ribicola*) and Dutch elm disease (*Ophiostoma novo-ulmi*) greatly altered the health and makeup of Minnesota's forests over the last century. Oak wilt (*Ceratocystis fagacearum*) has proven difficult to manage even though we have the tools available to prevent and control this tree killer. Concerns about the possible introduction of sudden oak death were proven to be unfounded following several years of survey after nursery stock was shipped into Minnesota from infested nurseries in the western U.S. However, more threats loom in the continuing fight against exotic diseases such as pine shoot blight (*Diplodia pinea*) and bur oak blight (*Tubakia sp.*). Native pests continue to operate in their persistent and cyclic manner. Monitoring forest damage and surveying for insects and pathogens are crucial to predicting and managing Minnesota's future forest resources.

What we found

Insects, pathogens, weather events, fire, and other factors cause damage and losses in forests throughout Minnesota every year. Since 1954, the eastern spruce budworm (*Choristoneura fumiferana*) has defoliated balsam fir and white spruce annually, establishing itself as the most persistent damaging agent in the State. The acres defoliated by spruce budworm increased steadily from 83,200 acres in 2004 to a high of 101,390 acres in 2007 before falling back to 41,263 in 2008. Widespread, scattered mortality has resulted, but a few trees have survived to become the seed trees for the replacement forest.

Another defoliator, the forest tent caterpillar (FTC), (*Malacosoma disstria*), is generally active somewhere in the State and at outbreak levels that often last 3 to 4 years, resulting in widespread dieback, decline, and mortality of especially aspen and birch. Populations have remained at low levels over the period, with annual defoliation ranging from 9,800 to 23,000 acres. However, previous outbreaks of FTC, in combination with spring frost and drought, resulted in 410,000 acres of aspen forests in 2004 with thin crowns and dwarfed leaves the size of nickels to quarters.

Other significant damage agents active from 2004 to 2008 were annual jack pine budworm (*Choristoneura pinus*) defoliation, from more than 75,000 acres in 2005 to just over 2,000 acres in 2008; the introduced larch casebearer (*Coleophora laricella*) defoliated 4,700 to 17,400 acres annually; larch beetles (*Dendroctonus simplex*) caused about 80 percent cumulative mortality of larch on about 65,000 acres during the period; and (black) ash decline from a variety of factors went from 27,000 acres in 2004 to about 2,000 acres in 2008.

Since 2004, Minnesota has been a formal member of the Gypsy Moth Slow the Spread (STS) Foundation. The STS Action Area is moved annually based on trap catch data and to cover the areas where moth populations are building. A rapid increase of moths trapped in 2008 (Fig. 42) indicates that the main gypsy moth (*Lymantria dispar*) population is getting closer to Minnesota's eastern border. Specifically, the shoreline of St. Louis County, south to Carleton and Pine Counties, had an unprecedented number of moths. Moth numbers were high in the southeast part of the State where three counties (Houston, Winona, and Wabasha) accounted for a substantial 2,489 moths (20 percent of the

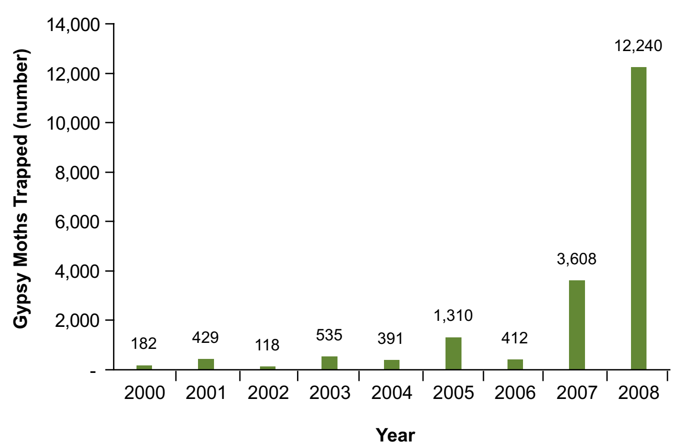

Figure 42.—Gypsy moths trapped in Minnesota, 2000-2008.

statewide total and 78 percent of the southern total). Evidence of reproducing gypsy moth populations was found on two sites in the Twin Cities metropolitan area.

The Minnesota Department of Agriculture coordinated the treatment of 85,038 acres within the STS Action Area in 2008. Six treatment blocks along the north shore of Lake Superior were identified and treated based on historic trap catches in the area. Treatments were in response to a record trapping year in 2007. Most of the high populations bordered the lakeshore so all treatment boundaries were near the shoreline. One area of high moth concentrations appeared inland, nearly overlapping a previous treatment in 2006. As the gypsy moth front moves closer to Minnesota, treatment acreage is expected to increase to meet the statewide objective of decreasing spread rates from 15 miles per year to less than 6 miles per year.

Emerald ash borer (*Agrilus planipennis*) was found in St. Paul in 2009. Quarantine was enacted quickly in Hennepin and Ramsey Counties. Studies of EAB-infested trees indicate that the St. Paul infestation dates back to 2006, making this one of the quickest discoveries of an EAB infestation. Ash makes up 50 percent of the lowland hardwood forest cover type in Minnesota, and the State has the third highest volume of ash in the U.S. Based on a survey in 2006, there are more than 3 million ash trees that are publicly owned in municipalities across the State. The quick find will enable managers to better prepare for the inevitable spread to all ash species in Minnesota.

Ash trees make up 8 percent of the total all live volume on Minnesota's forest land and are well distributed across the State (Fig 43). Ash is a component of more than 4.1 million acres of Minnesota forest land. It constitutes the majority of all live volume in a stand on 1.0 million acres and at least 25 percent of the stand volume on 1.7 million acres of forest land.

Since 2004, damage agents have been active, sometimes on some of the same acreages at the same time. Trees that are repeatedly damaged often sustain measurable growth loss, which in turn, sometimes results in mortality. Figure 44 shows areas of the State where forested lands have sustained damage from at least one agent detected by aerial survey from 2004 to 2008.

What this means

Weather results in greater losses to the forests of Minnesota than insects and disease, but it is the combination of weather, insects, and disease that is most lethal. Damage from high winds kills or wounds trees and provides habitat for beetles. Periods of drought and flood decrease the resistance of trees to insects and disease. The combination of environmental stresses and endemic pathogens leads to periods of greater than average mortality. Future concerns, however, may lie not with sporadic outbreaks of mortality from resident pathogens but rather with new pests such as the European gypsy moth, sudden oak death, and emerald ash borer.

The emerald ash borer in particular is likely to have a profound impact on Minnesota's forests. Over time it is expected to spread throughout the State, impacting 24 percent of Minnesota's forests by eliminating the ash component.

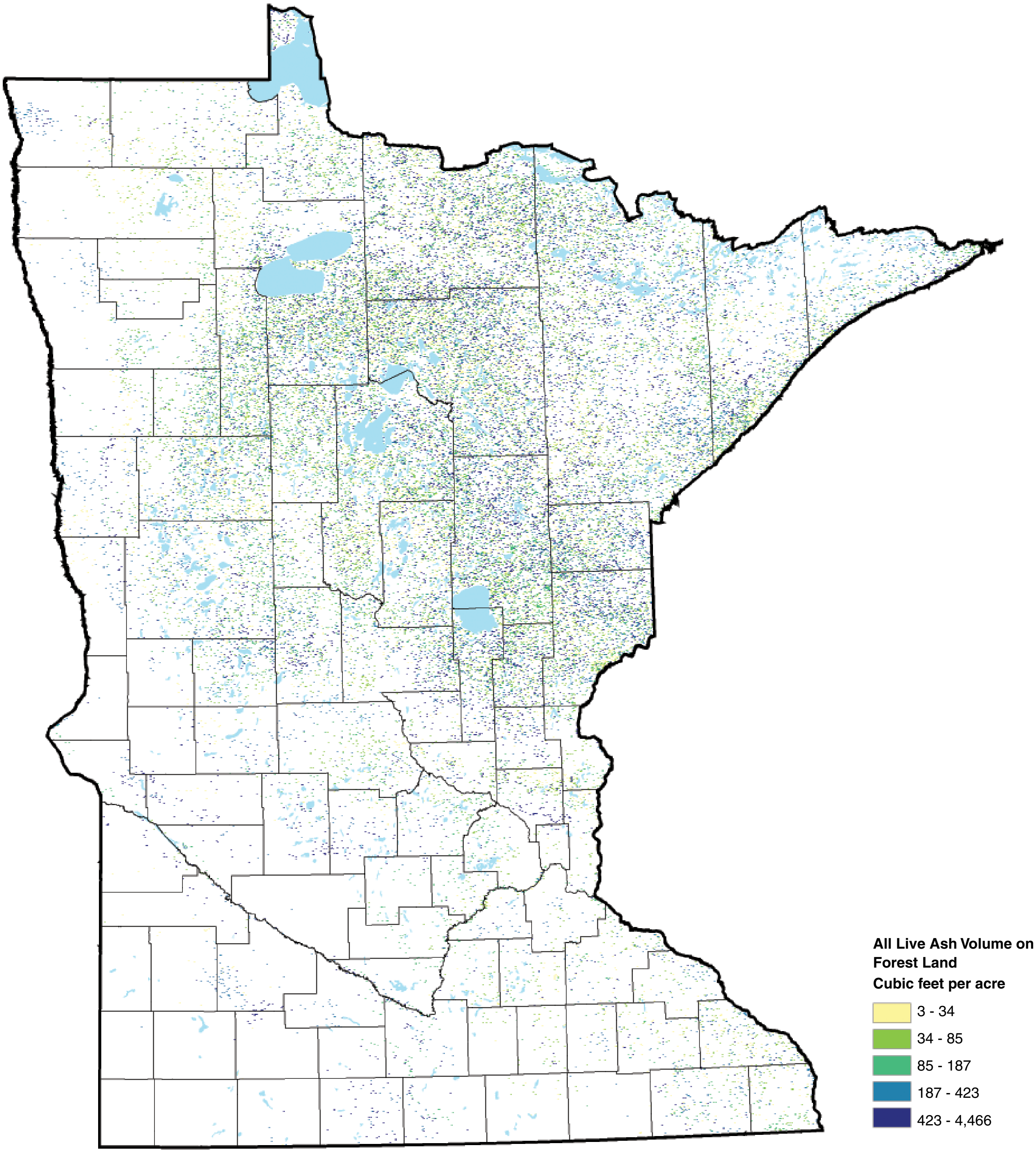

Figure 43.—Live-tree volume of ash on forest land, Minnesota, 2008.

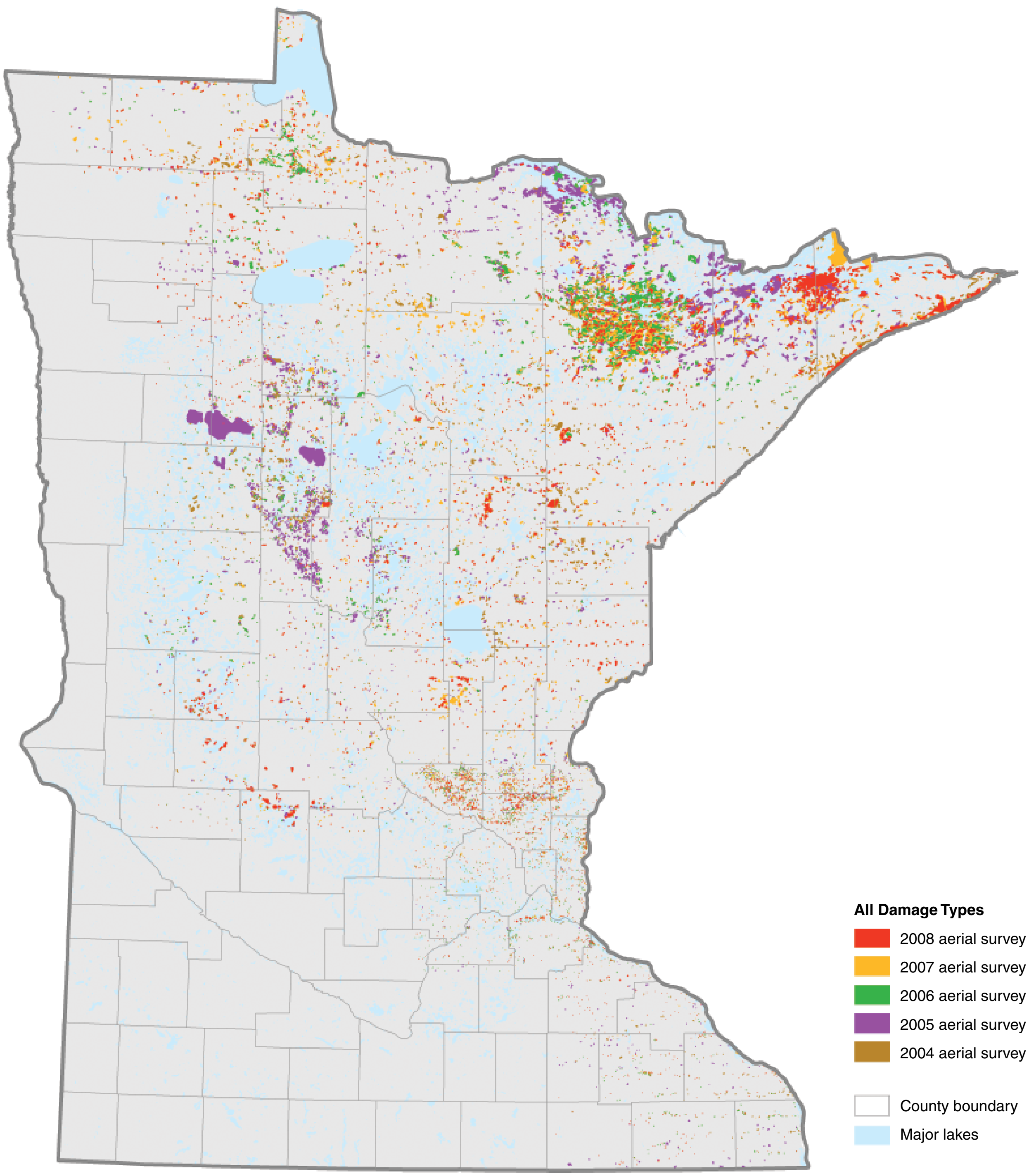

Figure 44.—Areas with damage (all types) mapped by aerial survey, 2004-2008 (Forest Health Protection, St. Paul Field Office).

Soils

Background

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

What we found

The calcium:aluminum ratio in the soil is an important predictor of several measures of crown vigor, and the effect varies across tree species.

The uncompacted live crown ratio is determined by dividing the live crown length by the actual tree length. Larger values are associated with healthier trees; low values of this ratio can be related to self pruning and shading from other tree crowns, but other reasons include defoliation due to dieback, and loss of branches due to breakage or mortality. The calcium:aluminum ratio is a significant predictor of the uncompacted live crown ratio (Fig.45). However, the effect in Minnesota is different from that in eastern states: the lowest crown ratios in the State overall are associated with low levels of aluminum, but this effect varies across tree species. For example, the live crown ratios of sugar maple and quaking aspen decrease with increasing aluminum (decreasing calcium:aluminum ratio). By contrast, the live crown ratios of American basswood and paper birch increase at the highest aluminum values (Fig 46).

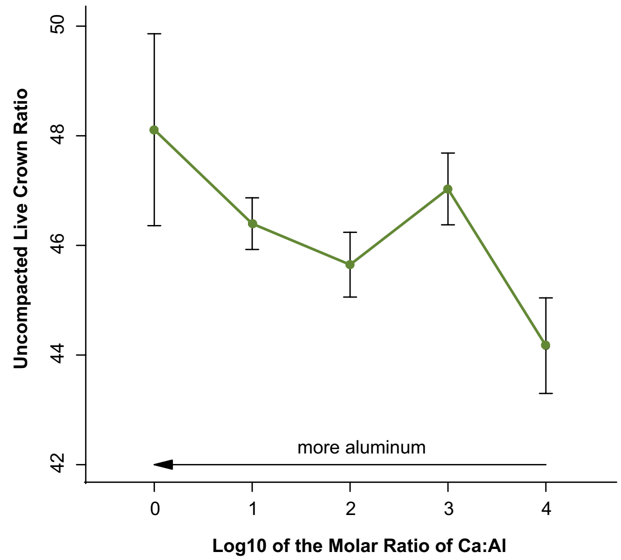

Figure 45.—Uncompacted live crown ratio percent is significantly related to the amount of calcium and aluminum in the soil, Minnesota, 2008.

Crown density is another measure of tree health, and again, there are linkages with soil aluminum: increasing amounts of aluminum generally lead to lower crown density (Fig. 47). As before, the effect varies across species. Quaking aspen appears to have the strongest negative response; crown density decreased more in aspen than in any other species (Fig. 48).

What this means

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

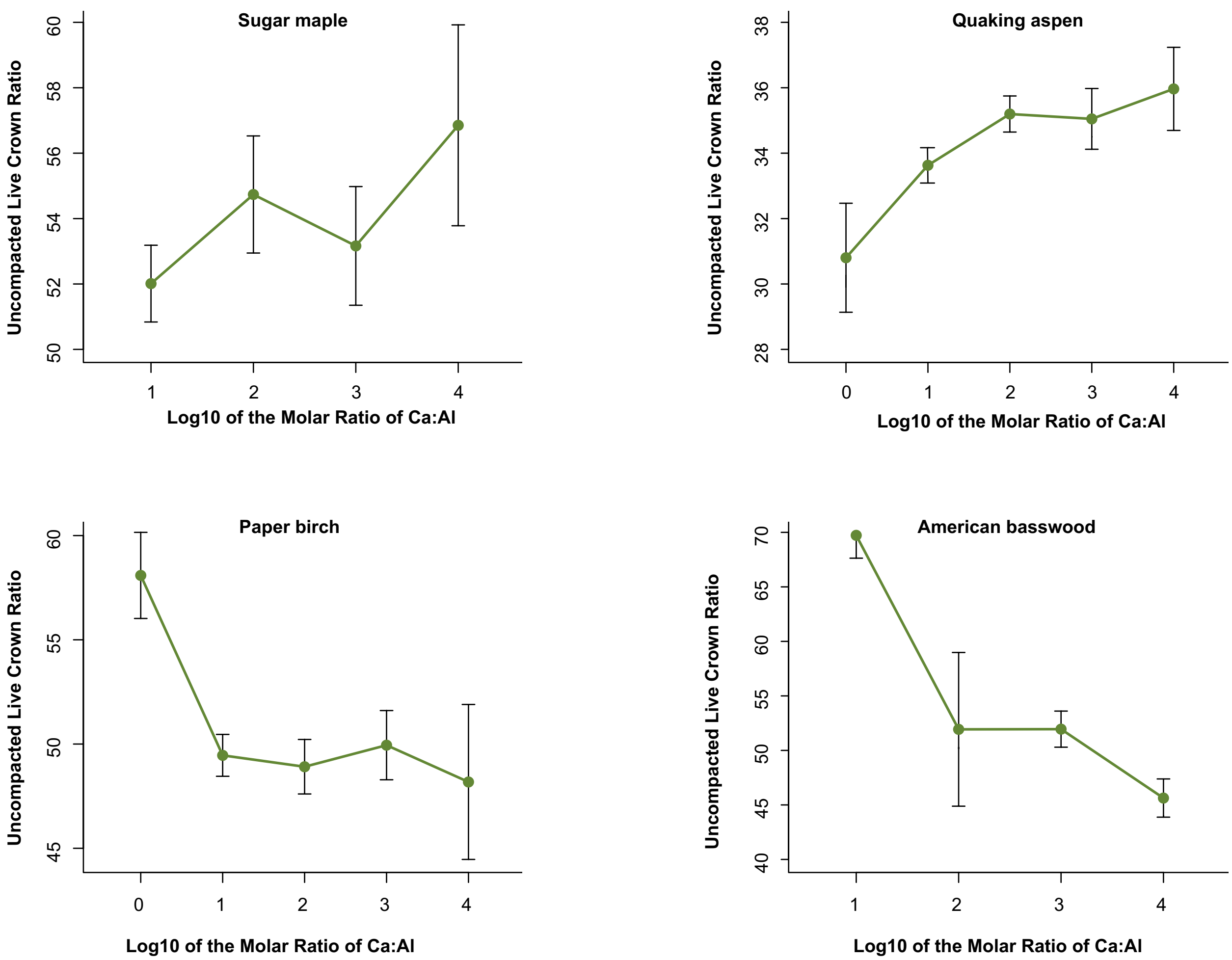

Figure 46.—The effect of calcium and aluminum on the uncompacted live crown ratio percent varies by species, Minnesota, 2008.

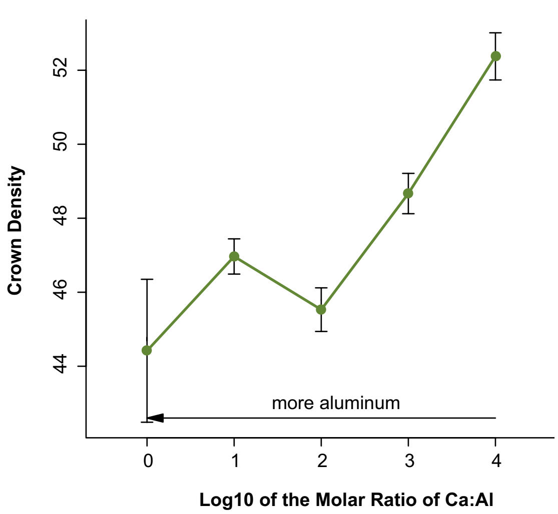

Figure 47.—Increasing amounts of aluminum (falling Ca:Al ratios) generally lead to lower crown density percent, Minnesota, 2008.

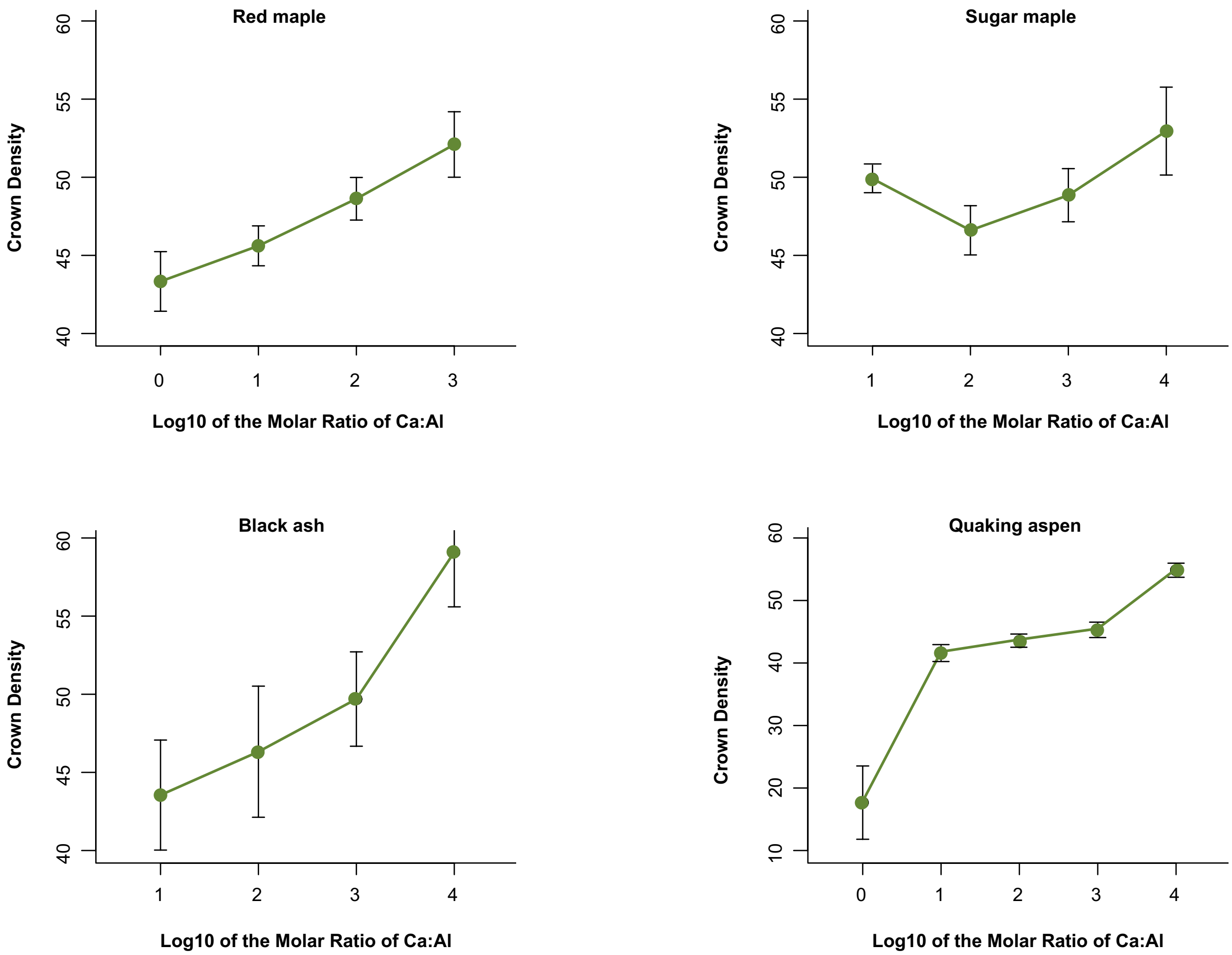

Figure 48.—The effect of calcium and aluminum on crown density percent varies by species, Minnesota, 2008.

Focus Issues

Tettegouche State Park. Photo used with permission of Minnesota Dept. of Natural Resources.

Land Use Change

Background

Information on land use change is important for understanding the future direction of land use in Minnesota. The estimated area of forest land in pre-settlement times was 31.5 million acres (Marschner 1930). Most of the change in forest land area occurred before the first forest inventory in the 1930s. The focus here will be on the change in forest area between 2003 and 2008.

What we found

Approximately 31 percent of Minnesota was forested in 2008. Twenty-nine percent of the area of Minnesota remained forested over the entire period from 2003 to 2008 (Fig 49). Two percent of Minnesota's area converted to forest land from nonforest land. Lands that convert to forest land are typically referred to as reversion because we assume that in pre-settlement times the lands had been forested and were now reverting back to their original land use. Sixty-nine percent of Minnesota was classified as nonforest in 2008. Sixty-eight percent of Minnesota's area remained nonforest (land and water) over the period from 2003 to 2008. One percent of the area of Minnesota converted from forest land to nonforest land. Lands that convert from forest land to nonforest land are typically referred to as diversion.

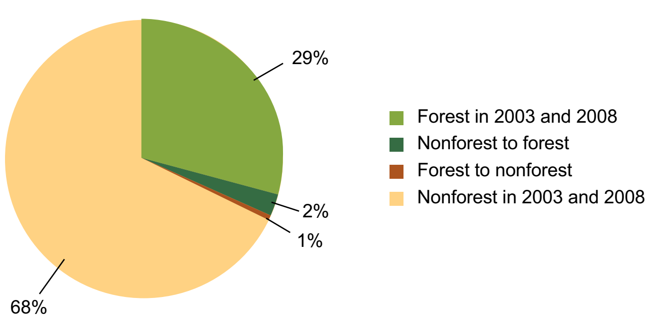

Figure 49.—Land use change, Minnesota, 2003-2008.

Sixty-six percent of reversions come from two sources: marsh (43 percent) and agricultural land (23 percent) (Fig. 50). The remaining one-third of reversions come from pasture (11 percent), urban (10 percent), water (6 percent), rights-of-way (5 percent), wooded strips/windbreaks (1 percent), and other (1 percent).

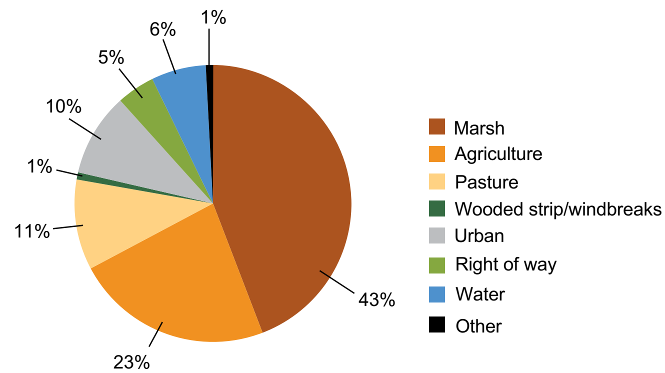

Figure 50.—Forest land reversions by previous land use, Minnesota, 2003-2008.

One-third of the losses to forest land were due to diversion to marsh (Fig. 51). The other two-thirds of diversions were due to urbanization (26 percent), agriculture (9 percent), rights-of-way (9 percent), water (9 percent), pasture (8 percent), wooded strips and windbreaks (5 percent), and other (1 percent).

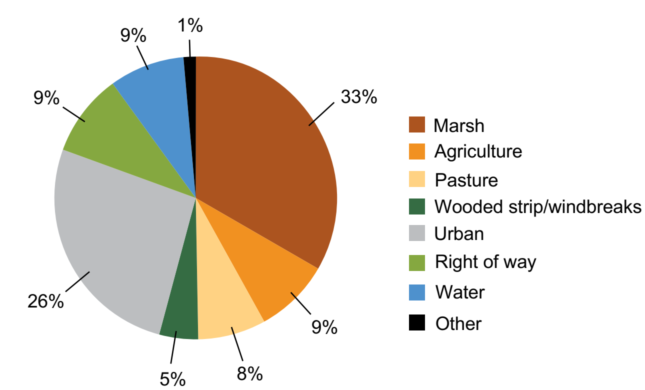

Figure 51.—Forest land diversions by current land use, Minnesota 2003-2008.

What this means

The forest land area of Minnesota is, for the most part, fairly stable. Approximately 96.3 percent of the land that was forested in 2003 remained forested in 2008. About 3.7 percent of the area that was forested in 2003 diverted to nonforest land uses, but this was more than offset by reversions to forest land that were equivalent to approximately 8 percent of the 2003 forest land area. The net effect was a 4.7-percent increase in the area of forest land between 2003 and 2008.

Low-lying areas appear to move between forest and nonforest classifications due to weather (drought/flooding) and other natural causes such as beaver dams. These conditions are often not permanent and therefore movement is likely to continue in the future. Other changes in land use are due primarily to socioeconomic factors.

Forest Patterns

Background

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

What we found

National Land Cover Dataset (NLCD) imagery from 2001 (Vogelmann et al. 2001) was reclassified to create a six-class land cover map of Minnesota (Fig. 52). With this map, forest pixels were characterized according to their location in relation to developed edges, or edges due to urban development, agriculture, or barren land uses. Environmental differences at the forest edge, also referred to as edge effects, can penetrate a forest patch for tens of meters (Collinge 1996). A commonly used threshold for edge effects is 100 to 300 feet, or approximately 30 to 90 m, after which interior forest conditions begin (Riemann et al. 2009). Forest pixels were classified as being within 90 m of a developed edge or greater than 90 m from a developed edge (Fig. 53). According to this analysis, nearly one-fourth (24%) of Minnesota's forest land is subject to edge effects and lacks interior forest conditions.

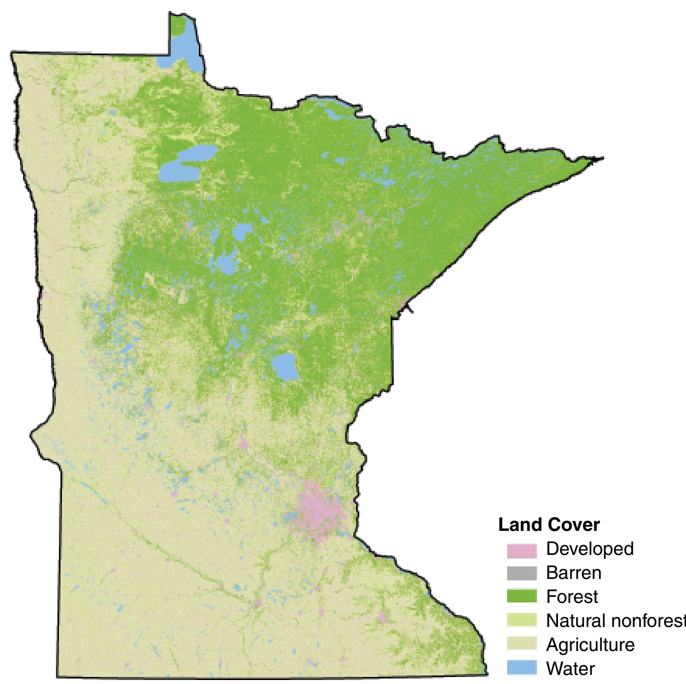

Figure 52.—Minnesota land cover derived from National Land Cover Dataset, 2001.

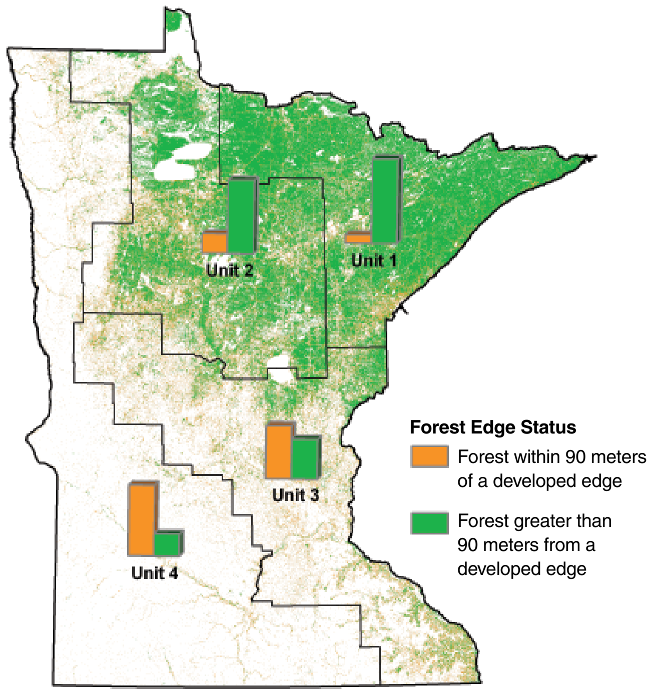

Figure 53.—Map of forest edge status derived from National Land Cover Dataset classification, Minnesota, 2001.

What this means

Overall, forest makes up one-third of Minnesota's land base. How this forest land is arranged across the landscape affects ecological processes. Based on the map pixel analysis, the majority of forest (76 percent) was classified as having interior conditions. However, this pattern is not consistent across the State because forest land is concentrated in the north-central and northeastern portions. An assessment by FIA unit shows that most of the forest in Units 1 and 2 is classified as interior forest, which is critical for maintaining biodiversity and healthy populations of native plants and wildlife. On the other hand, forest land in Units 3 and 4 is much more heavily fragmented, primarily due to agriculture and urban development, and is classified as forest edge. This has more serious implications for the forest, such as higher susceptibility to invasion by nonnative invasive species and other negative edge effects.

Nonindustrial Private Forest Land Owners

Background

The fate of the forest ultimately lies in the hands of those who control it – the forest land owners. FIA conducts the National Woodland Owner Survey (NWOS) to increase our understanding of who owns the forest, why they own it, and what they intend to do with it (Butler et al. 2005). It serves as the social complement to our inventory of the State's biophysical forest resources and allows a fuller understanding of the forest resources and the factors affecting them. Data presented here are based on survey responses from 743 randomly selected families and individuals who own forest land in Minnesota (Butler 2008). For additional information about the NWOS, please visit: www.fs.fed.us/woodlandowners.

What we found

In Minnesota, approximately 56 percent of the forest land is controlled by public agencies. State agencies, such as the Minnesota Department of Natural Resources, manage the bulk of these lands. But Federal agencies, including the U.S. Forest Service, and local agencies, particularly county agencies, also control significant acreages. These lands are managed for multiple objectives, ranging from nature protection to recreation to timber production, and all are managed for the public good.

The other 44 percent of the forest land is privately owned. A total of 194,000 families, individuals, trusts, estates, and other unincorporated groups of individuals, collectively referred to as family forest owners, control a third of the total forest land in the State. Corporations, tribes, and associations are the other private owners in Minnesota. Use of these lands is highly variable and depends on the objectives of the individual owners. Depending on the owner and property, the land may be managed for timber, wildlife, recreation, a combination thereof, or maybe not managed at all.

Land ownership patterns vary significantly across the State. In northern Minnesota, and in particular the northeastern part, the percentage of public ownership is very high. In other parts of the State, private ownership tends to dominate the landscape.

The 194,000 family forest owners in Minnesota are as diverse as the land they own. There are two very distinct ways of looking at forest ownership statistics - numbers of owners and numbers of acres. Although about half of the family forest owners own between 1 and 9 acres of forest land, two-thirds of the family forest land is in holdings of 20 to 199 acres (Fig. 54).

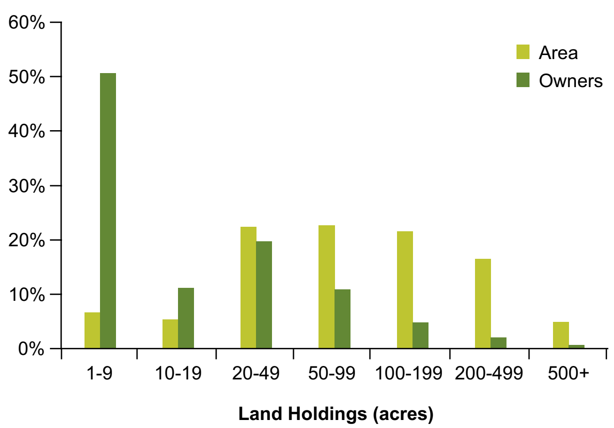

Figure 54.—Size of land holding of family forest owners, Minnesota, 2006.

The main reasons family forest owners own their forest land are related to the aesthetics and privacy their forests provide (Fig. 55). Although only 7 percent of the family forest owners, who own 16 percent of the family forest land, said that timber production was a primary objective, this does not imply that most owners object to actively managing their land. In fact, 27 percent of the family forest owners, who own 48 percent of the family forest land, have at some point commercially harvested trees on their land.

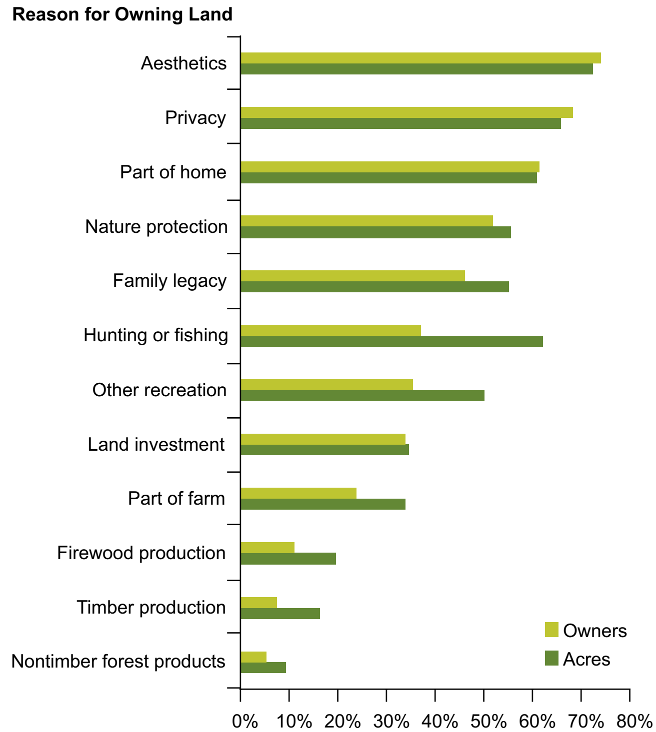

Figure 55.—Family forest owner reasons for owning forest land, Minnesota, 2006.

But two findings call into question whether harvesting was done to maximize the benefits to the owners and to the future forest stands. Only 5 percent of the owners, who own 17 percent of the family forest land, have a written forest management plan, and only 18 percent of the family forest owners, who own 29 percent of the family forest land, have sought forest management advice.

Landowner concerns include family legacy, trespassing, and high property taxes. Family legacy is both a primary objective and a common concern of many owners. This finding is related to the relatively advanced age of most owners, Thirty-four percent of the family forest owners are 65 years or over and control 32 percent of the family forest land. Eight percent of the family forest owners, who own 15 percent of the family forest land, plan to pass on or sell their land in the near future.

What this means

There is not a single right way to look at forest ownership statistics – numbers of owners or numbers of acres. The most appropriate way depends on the questions being asked, and often it is useful to examine both numbers. Although many professional foresters hesitate to call properties of fewer than 10 acres "forests," these acreages do cover a significant part of the landscape. Many play a critical role in providing environmental and social services and are often under most threat from development pressures and new insects and diseases. It is also likely that the number of smaller properties will continue to increase as larger properties are broken up, a process referred to as forest parcelization. And for those interested in forest policy, it is important to remember: trees don't vote, people do. There are many "large" properties across the State, both private and public, and they too provide vital goods and services – timber, recreation, and water, just to name a few. On these properties, traditional forestry practices are a good fit.

If we wish to influence or nudge forest owners, we need to understand their motivations and the factors that influence them (Thaler and Sunstein 2008). Designing programs specifically tailored for woodland retreat, working of the land, supplemental income, or uninvolved owners (Butler et al. 2007), versus all private landowners, will be much more effective. Another area for study is forest ownership dynamics. The next generation of landowners may have a very different relationship with the land.

Nonnative and Invasive Plant Species

Background

Introduced and invasive species can be detrimental to native forest ecosystems. Invasive species may displace native vegetation, sometimes dominating ecological niches previously occupied by native species, and reduce forest ecosystem diversity, resiliency, and wildlife habitat.

What we found

Information about trees obtained from 6,139 forested FIA field plots and information about understory vegetation obtained from 184 forested phase 3 plots measured in 2004-2008 may be used to assess the prevalence of introduced and invasive plant species. A total of 657 species were identified on the 184 vegetative diversity plots. Sixty-seven of these species are not native to Minnesota (Table 8).

Sixty-four of the 184 plots had at least one identifiable invasive or introduced species (http://nrs.fs.fed.us/fia/data-collection) (Fig. 56). Sixty-seven different invasive/introduced species were found on these 184 plots. Thirty-nine plots had 3 or more introduced or invasive species. The most prevalent invasive species was common dandelion (*Taraxacum officinale*) that occurred on 32 of the plots. Twenty-five plots had aster (*Aster* spp.) and 17 plots had common buckthorn (*Rhamnus cathartica*).

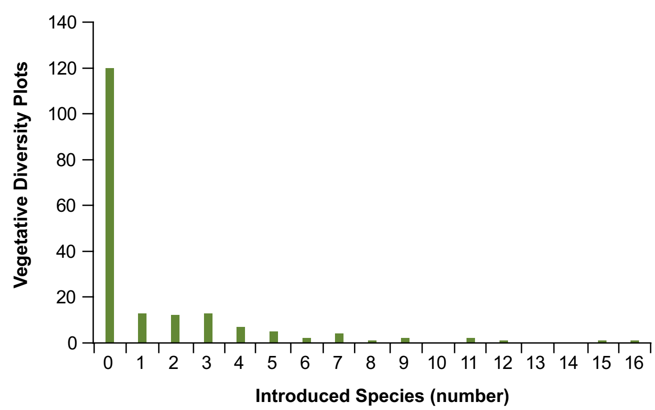

Figure 56.—Number of introduced species found on vegetative diversity plots, Minnesota, 2008.

The most common introduced tree species that occurs in the overstory is Siberian elm (*Ulmus pumila*), which was often planted in windbreaks. Other introduced tree species include Scotch pine (*Pinus sylvestris*), Austrian pine (*Pinus nigra*), apple (*Malus* spp.), larch (*Larix* spp.), blue spruce (*Picea pungens*), and a variety of poplars (*Populus* spp.).

Table 8.—Introduced and invasive plant species found on 184 phase 3 plots, Minnesota, 2008

Common Name	Scientific Name	Native/Introduced	Number of plots
Common dandelion	*Taraxacum officinale*	Native and Introduced to U.S.	32
Aster	*Aster*	Not MN	25
Common buckthorn	*Rhamnus cathartica*	Introduced to U.S.	17
Claspleaf twistedstalk	*Streptopus amplexifolius*	Native and Introduced to U.S.	13
Stinging nettle	*Urtica dioica*	Native and Introduced to U.S.	13
Kentucky bluegrass	*Poa pratensis*	Native and Introduced to U.S.	11
Black bindweed	*Polygonum convolvulus*	Introduced to U.S.	9
Common yarrow	*Achillea millefolium*	Native and Introduced to U.S.	9
Climbing nightshade	*Solanum dulcamara*	Introduced to U.S.	8
Lambsquarters	*Chenopodium album*	Native and Introduced to U.S.	6
White clover	*Trifolium repens*	Introduced to U.S.	6
Lesser burrdock	*Arctium minus*	Introduced to U.S.	5
Orange hawkweed	*Hieracium aurantiacum*	Introduced to U.S.	5
Red clover	*Trifolium pratense*	Introduced to U.S.	5
Smooth brome	*Bromus inermis*	Native and Introduced to U.S.	5
Common motherwort	*Leonurus cardiaca*	Introduced to U.S.	4
Curly dock	*Rumex crispus*	Introduced to U.S.	4
Prickly lettuce	*Lactuca serriola*	Introduced to U.S.	4
Redtop	*Agrostis gigantea*	Introduced to U.S.	4
Rugosa rose	*Rosa rugosa*	Introduced to U.S.	4
Timothy	*Phleum pratense*	Introduced to U.S.	4
Brittlestem hempnettle	*Galeopsis tetrahit*	Introduced to U.S.	3
Bull thistle	*Cirsium vulgare*	Introduced to U.S.	3
Canada thistle	*Cirsium arvense*	Introduced to U.S.	3
Common mullein	*Verbascum thapsus*	Introduced to U.S.	3
Sweet mock orange	*Philadelphus coronarius*	Introduced to U.S.	3
Wild parsnip	*Pastinaca sativa*	Introduced to U.S.	3
Catnip	*Nepeta cataria*	Introduced to U.S.	2
Creeping buttercup	*Ranunculus repens*	Introduced to U.S.	2
European black elderberry	*Sambucus nigra*	Native and Introduced to U.S.	2
Hoary false madwort	*Berteroa incana*	Introduced to U.S.	2
Narrowleaf cattail	*Typha angustifolia*	Introduced to U.S.	2
Quackgrass	*Elymus repens*	Introduced to U.S.	2
Redroot amaranth	*Amaranthus retroflexus*	Introduced to U.S.	2
Sweetbriar rose	*Rosa eglanteria*	Introduced to U.S.	2
Tall buttercup	*Ranunculus acris*	Native and Introduced to U.S.	2
American alumroot	*Heuchera americana*	Native to U.S. but not MN	1
Bell's honeysuckle	*Lonicera* x *bella*	Introduced to U.S.	1
Bladder campion	*Silene latifolia* ssp. *alba*	Introduced to U.S.	1
Blue spruce	*Picea pungens*	Native to U.S. but not MN	1
Bog aster	*Oclemena nemoralis*	Native to U.S. but not MN	1
Bouncingbet	*Saponaria officinalis*	Introduced to U.S.	1
Bunge's smartweed	*Polygonum bungeanum*	Introduced to U.S.	1
Common chickweed	*Stellaria media*	Introduced to U.S.	1

(Table 8 continued on next page)

(Table 8 continued)

Common Name	Scientific Name	Native/Introduced	Number of plots
Common sheep sorrel	*Rumex acetosella*	Introduced to U.S.	1
Common tansy	*Tanacetum vulgare*	Introduced to U.S.	1
Creeping jenny	*Lysimachia nummularia*	Introduced to U.S.	1
Ground ivy	*Glechoma hederacea*	Introduced to U.S.	1
Japanese brome	*Bromus japonicus*	Introduced to U.S.	1
King of the meadow	*Thalictrum pubescens*	Native to U.S. but not MN	1
Laurel willow	*Salix pentandra*	Introduced to U.S.	1
Maidenstears	*Silene vulgaris*	Introduced to U.S.	1
Marshpepper knotweed	*Polygonum hydropiper*	Introduced to U.S.	1
Mountain bugbane	*Cimicifuga americana*	Native to U.S. but not MN	1
Narrowleaf hawksbeard	*Crepis tectorum*	Introduced to U.S.	1
Ohio goldenrod	*Oligoneuron ohioense*	Native to U.S. but not MN	1
Oxeye daisy	*Leucanthemum vulgare*	Introduced to U.S.	1
Perennial ryegrass	*Lolium perenne*	Introduced to U.S.	1
Plantain lily	*Hosta*	Not MN	1
Prostrate knotweed	*Polygonum aviculare*	Introduced to U.S.	1
Queen Anne's lace	*Daucus carota*	Introduced to U.S.	1
Silky dogwood	*Cornus amomum*	Native to U.S. but not MN	1
Spotted ladysthumb	*Polygonum persicaria*	Probably Introduced to U.S.	1
Sweetberry honeysuckle	*Lonicera caerulea*	Native to U.S. but not MN	1
Tatarian honeysuckle	*Lonicera tatarica*	Introduced to U.S.	1
Waxyleaf aster	*Symphyotrichum undulatum*	Native to U.S. but not MN	1
Yellow sweetclover	*Melilotus officinalis*	Introduced to U.S.	1

What this means

Based on the vegetation diversity indicator, invasive or introduced species are found on just over one-third of the forested plots in Minnesota. The extent to which these introduced or invasive species cause harm cannot be assessed at this time; however, the potential exists for these species to reduce the overall diversity and health of Minnesota's forests. Invasive or introduced species appear to occur on recently disturbed sites or nonforest boundary areas, where low stand densities allow for establishment of new species.

Invasive tree species make up less than one-tenth of 1 percent of the tree biomass in Minnesota. Still, over time, the potential exists for native species displacement and reduction in the value and health of Minnesota's forests.

Wildlife Habitat

Background

Habitat requirements vary by species. Some species require interior mature forests, other species require forest edge, and still others require both habitats at different times of the year or of their life cycle. Addressing habitat requirements by individual species is beyond the scope of this report. Broad characterizations of wildlife habitat using FIA data can be made, however, by looking at several indicators. Information from these indicators may also help to identify areas lacking adequate habitat while establishing a baseline of monitoring data. Mature forests, the presence or absence of snags, the quantity of coarse woody debris, and forest spatial patterns are all important descriptors of forest wildlife habitat.

What we found

Diverse stages of stand development are found across the forests of Minnesota (Fig. 57).Generally, more mature forests (based on mean tree size and stand density assessments) are found in the prairie areas of Minnesota, whereas younger stands are more typically found in northern Minnesota where removals are highest.

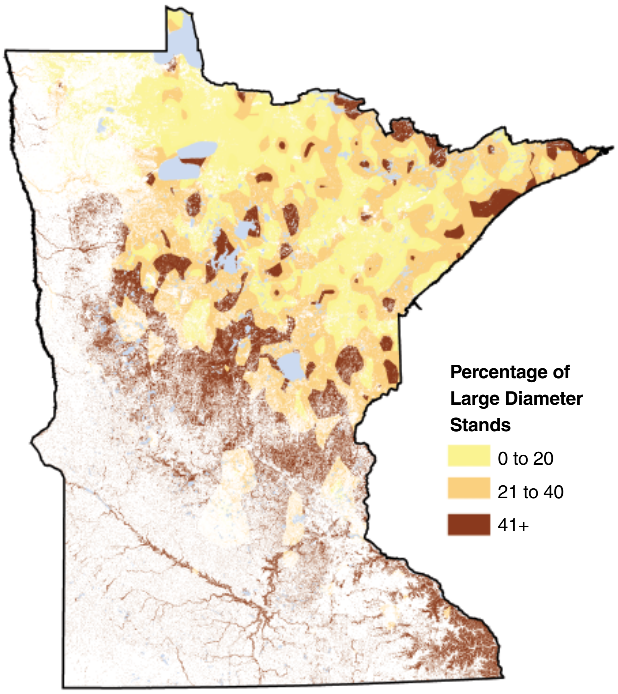

Figure 57.—Interpolated map (inverse-distance weighting) proportion of forest land that is in large-diameter stands, Minnesota, 2008.

Standing-dead or snag trees are important habitat for birds and mammals. The downy woodpecker and 31 other Minnesota forest bird species rely on tree cavities and snags for feeding and nesting (Pfannmuller and Green 1999). Most cavity-nesting birds are insectivores and help control the insect population. Additionally snags are used as a source of food by 26 mammal species and are a critical component of wildlife habitat (University of Minnesota Extension Service 2005).

The abundance of snags is highly variable across the forests of Minnesota, although the greatest amounts appear to occur in the northeastern part of the State, probably due largely to the blowdown of July 4, 1999 (Fig. 58).

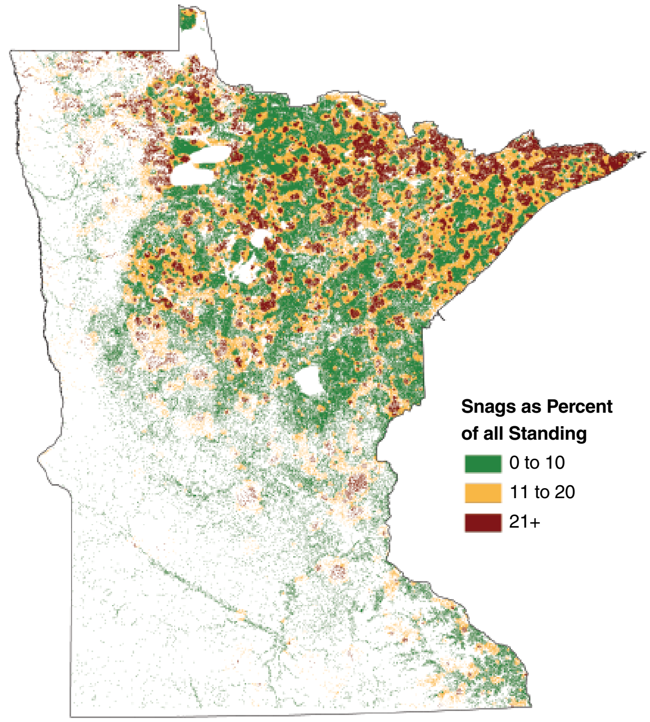

Figure 58.—Interpolated map (inverse-distance weighting) number of standing dead trees as a percent of standing live and dead trees, Minnesota, 2008.

In Minnesota, for every 100 live trees more than 5 inches in diameter there are 14 snag trees. There are 13.6 snags per 100 live hardwoods and 14.8 snags per 100 live softwoods.

The percent of standing dead to live trees is slightly higher for national forest ownership (17.9) than for state and local government ownership (13.9), and private ownership (12.5). Part of the reason for this may be differences in stand age. The average stand age for national forests is 58 years, state and local government 55 years, and private ownership 53 years.

The largest quantities of coarse woody debris are found in areas affected by wind disturbances. Most recently these areas include the BWCAW and prairie border forests.

What this means

Current inventory data indicate diverse and abundant forest habitat (snags, coarse woody debris, and forest patterns) to support numerous wildlife species across Minnesota. However, data are insufficient to project trends or draw conclusions about individual wildlife species. For species that depend on continuous forest cover in mature forests, there is evidence that the area of mature forest is increasing across Minnesota but that there has been a decrease in the area of interior forests. For species that require both the cover of mature forests and foraging areas of nonforest environments, the continued maturation and fragmentation of Minnesota's forests will maintain these habitat intermixes.

Timber Product Output

Background

Timber harvesting produces economic benefits for persons involved in timber ownership, management, marketing, harvesting, hauling, and distribution to processing mills. Approximately 16,048 people are employed in wood product manufacturing (Bureau of Census NAICS code 321) and 12,394 are employed in paper manufacturing (NAICS code 322). The total payroll for these two sectors of the Minnesota forest economy was estimated at $1.3 billion (8 percent of all manufacturing in Minnesota). The value of forest products manufacturing shipments was estimated at $8.8 billion in 2007 (U.S. Census Bureau 2007).

What we found

Surveys of Minnesota's wood-processing mills are conducted periodically to estimate the amount of wood volume processed into products (Fig. 59). The last survey was conducted in 2007. The key sectors of the forest products industry include sawmills, pulp and particleboard (flakeboard, waferboard, oriented strandboard, and medium-density fiberboard) mills, and secondary processors. Of increasing importance are co-generation facilities utilizing wood fiber for energy. There are now six cogeneration plants in Minnesota using more than 200,000 green tons of woody biomass per year, two plants using more than 50,000 green tons, and 30 plants using less than 50,000 green tons (Minnesota DNR Utilization and Marketing 2010).

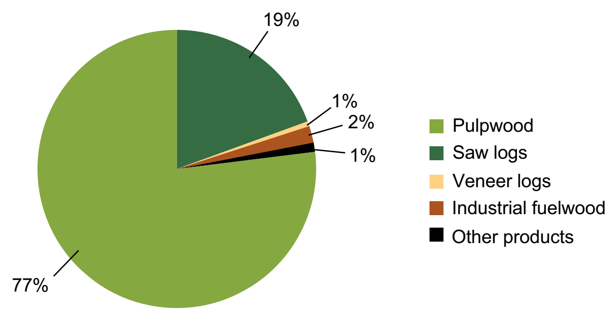

Figure 59.—Industrial roundwood production by product, Minnesota, 2007.

Most primary processing takes place in northeastern Minnesota where the majority of the timber resource is located. There are seven pulpwood-using mills in Minnesota, five of which produce paper: UPM-Blandin (Grand Rapids), Boise (International Falls), Verso (Sartell), NewPage (Duluth), and Sappi Fine Paper Company (Cloquet). Two mills specialize in hardboard and specialty products: International Bildrite (International Falls), and Georgia-Pacific (Duluth). A third hardboard and specialty mill, located in the Twin Cites suburb of Shakopee and owned by the Certainteed Corporation, closed in 2007.

Minnesota's oriented strandboard (OSB) and engineered wood products industry is also located in the north. OSB plants are located in Two Harbors (Louisiana-Pacific) and in Solway (Norbord Minnesota). Four OSB plants have closed since 2006: Grand Rapids (Ainsworth Lumber), Bemidji (Ainsworth Lumber and Northwood Panelboard), and Cook (Ainsworth Lumber). A laminated strandboard plant, located near Deerwood (Weyerhaeuser), closed in 2007 in response to slow customer demand.

Minnesota produced 2.3 million cords of pulpwood (including mill residues) in 2007 (Piva, in prep), down from nearly 3.0 million cords of pulpwood in 2002 (Piva 2005). Pulpwood includes all fiber-based products made from roundwood including particleboard, oriented strandboard (OSB), waferboard, and engineered lumber. Aspen roundwood accounted for 66 percent of the roundwood used for pulpwood production, 12 percent came from other hardwoods, and 22 percent came from softwoods.

The seven pulp mills, two OSB mills, and one laminated structural lumber mill in Minnesota reported consuming 2.4 million cords in 2007, down from 3.6 million cords in 2002 (Piva 2005), a decrease of 24 percent from 2006. Minnesota's pulp and particleboard mills acquired 9 percent of their raw material from out-of-State sources in 2007. Wisconsin supplied more than 68 percent of the imported wood material, with most of the remainder coming from Canada.

Almost 217 million cubic feet of industrial roundwood was harvested for the primary wood-using industry from Minnesota's forest land in 2007, down from the 278 million reported in 2003. Aspen accounted for 53 percent of the total harvest (Fig. 60). Spruce, red pine, and white birch were other important species, but combined made up only 21 percent of the total harvest. Roundwood harvested for pulp and composite panel mills accounted for 48 percent and 29 percent, respectively, of the total harvest. Saw logs were the other major forest product, with 19 percent of the harvest. Other products harvested were veneer, excelsior and shavings bolts, poles and posts, cabin logs, and other miscellaneous products.

More than 95 percent of the industrial roundwood harvested in Minnesota was processed by Minnesota mills. Of the 217 million cubic feet of industrial roundwood produced, 94 percent came from growing-stock sources. The remainder of the industrial roundwood came from cull trees, limbwood, dead trees, and saplings.

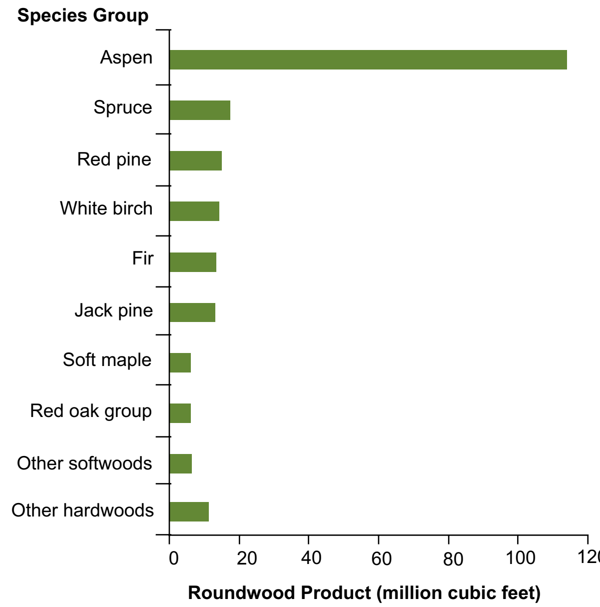

Figure 60.—Industrial roundwood production by species group, Minnesota, 2007.

In the process of harvesting industrial roundwood from Minnesota's forest land, 12 million cubic feet of growing-stock material and 96 million cubic feet of non-growing-stock material were left on the ground as logging residue and slash.

In 2007, Minnesota's primary wood-using mills generated 1.5 million green tons of mill residues. Sixty-three percent of the mill residues were used for industrial fuel (Fig. 61). Another 11 percent were used by pulp and composite panel mills. Only 1 percent of the mill residues were not used for fiber products, fuelwood, mulch, small dimension lumber, or other uses.

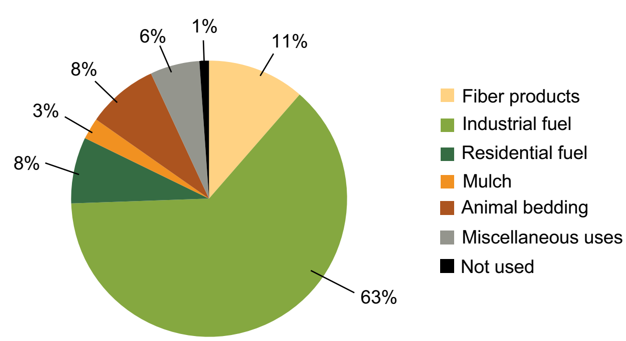

Figure 61.—Disposition of mill residues generated by primary wood-using mills, Minnesota, 2007.

What this means

The timber products industry plays a vital role in the economy of rural Minnesota. Based on current volumes and a healthy growth-to-removals ratio of 1.4 , there is the biological potential to sustainably increase harvest levels. The extent to which this potential is realized depends on many things including markets, stumpage prices, and landowner objectives.

Data Sources and Techniques

Frontenac State Park, Deborah Rose.

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, and 2003 (Zon 1935, Cunningham et al 1958, Stone 1966, Jakes 1980, Leatherberry et al. 1995, Miles et al. 2007).

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. The annual inventory was initiated in Minnesota in 1999.

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

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

New algorithms were used for the 2008 inventory to assign forest type and stand-size class to each condition observed on a plot. These algorithms are being used nationwide by FIA to provide consistency from state to state. As a result, changes in forest type and stand-size class between annual inventories will reflect actual changes in the forest and not changes due to differences between algorithms. The list of recognized forest types, groupings of these forest types for reporting purposes, models used to assign stocking values to individual trees, definition of nonstocked (stands with a stocking value of less than 10 percent for live trees), and names given to the forest types changed with the new annual inventory algorithms. Identical classification procedures were used for the 2003 and 2008 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.

Sampling Phases

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

Phase 1

Aerial photographs, digital orthoquads (DOQs: digitally scanned aerial photograph), and satellite imagery are used for initial plot measurement via remotely sensed data and stratification. Phase 1 plot measurement consists of observations of conditions at the plot locations using aerial photographs or DOQs. Analysts determine a digitized geographic location for each field plot and a human interpreter assigns the plot a land cover/use. Lands satisfying FIA's definition of forest land include commercial timberland, some pastured land with trees, forest plantations, unproductive forested land, and reserved, noncommercial forested land. In addition, forest land requires minimum stocking levels, a 1-acre minimum area, and a minimum bole-to-bole width of 120 feet with continuous canopy. Forest land excludes wooded strips and windbreaks less than 120 feet wide and idle farmland or other previously nonforest land that currently is below minimum stocking levels. All plot locations that could possibly contain accessible forest land are selected for further measurement via field crew visits in phase 2.

Phase 2

Phase 2 of the inventory consists of the measurement of the annual sample of Minnesota field plots. Current FIA precision standards for annual inventories require a sampling intensity of one plot for approximately every 6,000 acres. FIA has divided the entire area of the United States into nonoverlapping hexagons, each of which contains 5,937 acres (McRoberts 1999). This array of plots is designated the Federal base sample and is considered an equal probability sample; its measurement in Minnesota is funded by the Federal Government. In Minnesota a single-intensity sample was completed in 1999. Beginning in 2000, the State of Minnesota provided additional resources to increase the sampling intensity. Double-intensity sampling was completed in 2000 except for the Boundary Waters Canoe Area Wilderness (BWCAW) and Voyageurs National Park where a single-intensity sample was completed. A double-intensity sample was also completed in 2001 through 2008 except in the BWCAW where a single-intensity sample was completed. The total Federal base sample of plots was systematically divided into five interpenetrating, nonoverlapping subsamples or panels. Each year, the plots in a single panel are measured; panels are selected on a 5-year, rotating basis (McRoberts 1999). For estimation purposes, the measurement of each panel of plots can be considered an independent systematic sample of all land in a state.

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

Phase 3

The third phase of the enhanced FIA program focuses on forest health. Phase 3 is administered by FIA with consultation from other Forest Service programs, other Federal agencies, state natural resource agencies, universities, and the FHM program. The FHM program consists of four interrelated and complementary activities: detection, evaluation, and intensive site-ecosystem monitoring, and research on monitoring techniques. Detection monitoring consists of systematic aerial and ground surveys designed to collect baseline information on the current condition of forest ecosystems and to detect changes from those baselines over time. Evaluation monitoring studies examine the extent, severity, and probable causes of changes in forest health identified through the detection monitoring surveys. Intensive site-ecosystem monitoring studies regionally specific ecological processes at a network of sites located in representative forested ecosystems. Research on monitoring techniques focuses on developing and refining indicator measurements to improve the efficiency and reliability of data collection and analysis at all levels of the program.

The ground-survey portion of the detection monitoring program was integrated into the FIA program as phase 3 in 1999. The phase 3 sample consists of a 1:16 subset of the phase 2 plots with one phase 3 plot for about every 95,000 acres. Phase 3 measurements are obtained by field crews during the growing season and include an extended suite of ecological data: lichen diversity and abundance, soil quality (erosion, compaction, and chemistry), vegetation diversity and structure, and down woody material. The incidence and severity of ozone injury for selected bioindicator species also are monitored as part of an associated sampling scheme. All phase 2 measurements are collected on each phase 3 plot at the same time as the phase 3 measurements. Additional information on the collection procedures used in phase 3 is available at: http://www.nrs.fs.fed.us/fia/topics/.

Phase 3 variables are selected to address specific criteria outlined by the Montreal Process Working Group for the conservation and sustainable management of temperate and boreal forests and are based on the concept of indicator variables. Observations of an indicator variable represent an index of ecosystem functions that can be monitored over time to assess trends. Indicator variables are used in conjunction with each other, P2 data, data from FHM evaluation monitoring studies, and ancillary data to address ecological issues such as vegetation diversity, fuel loading, regional air-quality gradients, and carbon storage. The phase 2 and phase 3 data of the enhanced FIA program are a primary source of reporting data for the Montreal Process Criteria.

Stratified Estimation

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

Strata construction methods used by NRS-FIA were developed to work well across the entire 24-state region. Using data on plot location (center of the center subplot), a percent canopy-density value was assigned to each plot. Plots were then aggregated into one of the five canopy cover classes based on the center of the center subplot. The canopy cover classification scheme consists of five groupings: 0 to 5, 6 to 50, 51 to 65, 66 to 80, and 81 to 100 percent. These groupings were based on observed natural clumping of pixel values.

In addition to the classification of each pixel into one of the five canopy cover classes, each pixel was assigned to an ownership class. In Minnesota, ownership layers, derived from the Minnesota DNR Data Deli (http://deli.dnr.state.mn.us/), were used to classify pixels into seven ownership classes: (1) Boundary Waters Canoe Area Wilderness, (2) Chippewa National Forest, (3) Superior National Forest, (4) Voyageurs National Park, (5) other public, (6) private, and (7) water. The largest ownership class based on pixel counts was private ownership at more than 39 million acres. Each pixel also was assigned to a county based on the location of the pixel center.

Stratified estimation requires two tasks. First, each plot must be assigned to a single stratum. Next, the proportion of each detailed stratum must be calculated (TM land-cover classification, ownership, and county group delineation). The first task assigns each plot to the stratum assigned for the pixel containing the center of the center subplot. The second task calculates the proportion of pixels in each stratum. The population estimate for a variable is calculated as the sum across all strata of the product of each stratum's observed proportion (from phase 1) and the variable's estimated mean per unit area for the stratum (from phase 2).

Field plot measurements are combined with phase 1 estimates in the data compilation and table production process. However, other tabular data can be generated at the Forest Inventory and Analysis Data Center Web page at http://www.fia.fs.fed.us/tools-data/. For additional information, contact: Program Manager, Forest Inventory and Analysis, Northern Research Station, 1992 Folwell Avenue, St. Paul, MN 55108 or State Forester, Minnesota Department of Natural Resources, 500 Lafayette Road, St. Paul, MN 55155.

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 Minnesota's 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.

Mapping Procedures

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

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The second full annual inventory of Minnesota's forests reports 17 million acres of forest land with an average volume of more than 1,000 cubic feet per acre. Forest land is dominated by the aspen forest type, which occupies nearly 30 percent of the total forest land area. Twenty-eight percent of forest land consists of sawtimber, 35 percent poletimber, 35 percent sapling/seedlings, and 2 percent is nonstocked. 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. Detailed information on forest inventory methods, data quality estimates, and important resource statistics can be found on the Statistics and Quality Assurance DVD included in this report.

KEY WORDS: inventory, forest statistics, forest health

DVD Contents

Minnesota's Forests 2008 (PDF)

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

Minnesota's Inventory Database (CSV file)

Minnesota's Inventory Database (Microsoft Access file)

Field guides that describe inventory procedures (PDF)

Database User Guides (PDF)

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