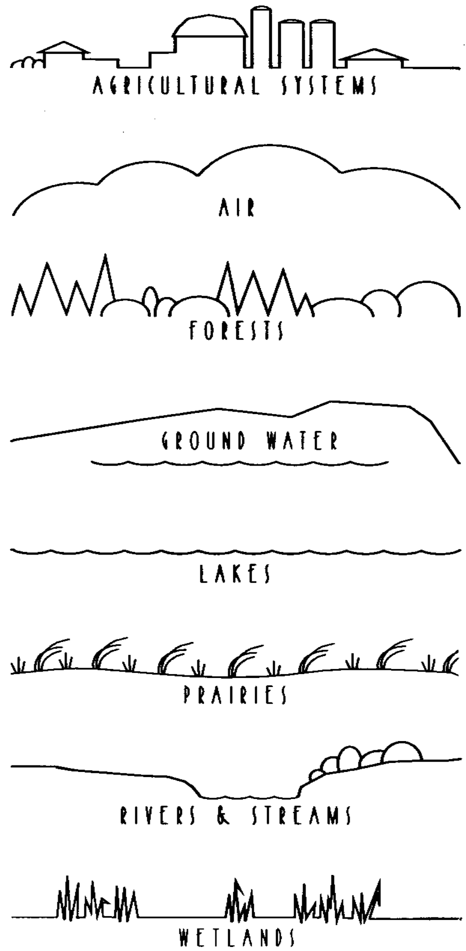
DEVELOPING ENVIRONMENTAL INDICATORS FOR MINNESOTA



Forests

The Environmental Indicators Initiative

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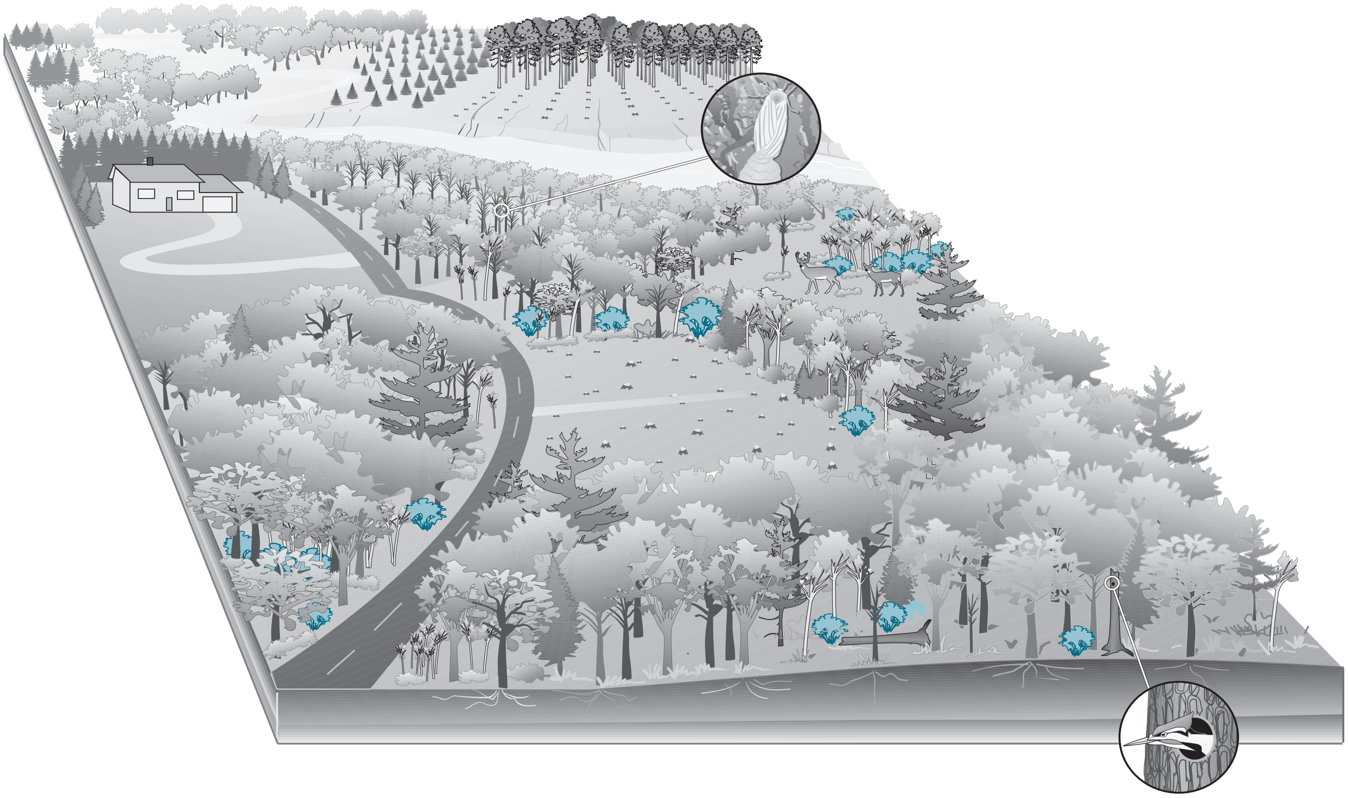


Citizens and decision makers use environmental indicators to help effectively manage and protect Minnesota's forests. Environmental indicators answer four questions.

What is happening to our forests?

Environmental condition can be assessed using indicators based on ecological characteristics of forests, including **extent and distribution of forest types, tree growth**, and **snag and woody debris density**.

Why is it happening?

Indicators of *human activities* that affect forests include **land areas converted to other uses, timber harvest by species**, and **introduction of exotic species**.

How does it affect us?

Changes in forest health may diminish the flow of *benefits*. Indicators of how we are affected include **economic benefits of timber harvest** and **water quality in forested watersheds**.

What are we doing about it?

Societal strategies to maintain or restore healthy forests include **implementation of forest management guidelines, regeneration strategies**, and **forest resource monitoring**.

In this chapter we outline important benefits from forest ecosystems, the key ecological characteristics that determine the health of forests, the pressures affecting forests today, the current status and trends relating to forests, and the most significant policies and programs that affect Minnesota forests. Throughout this chapter we give examples of indicators that provide important information about Minnesota forests.

HIGHLIGHTS

Benefits of Healthy Forests

- Provide cultural heritage and sense of beauty
- Sequester carbon and regulate changes in global nutrient cycles
- Contribute $7.8 billion in forest production to the state's economy
- Improve water quality by stabilizing soils and intercepting nutrients in runoff
- Provide wildlife habitat
- Regulate overland and subsurface water flows
- Provide recreation resources
- Enhance the resort industry

Important Ecological Characteristics

- Different forest types exist across the state, each with unique attributes and services
- Forest types are influenced by climate, landforms and soils, disturbance regimes, and land-use activities
- Size and number of canopy layers influence ecological function
- Disturbances affecting ecological function include fire, windthrow, grazing, pest outbreaks, and logging
- Human pressures may alter the frequency and intensity of natural disturbances
- Landscape patterns affect forest composition and wildlife

Pressures

- Forest fragmentation
- Diseases and pests (e.g., oak wilt, spruce budworm, gypsy moth)
- Timber harvesting
- Atmospheric pollutants (acid precipitation, ozone, greenhouse gases)
- Land conversion (roads, agriculture and urban development)
- Exotic species (e.g., buckthorn)
- Recreational activities

Status and Trends

- Less than 0.02% of old-growth maple-basswood forest remains
- Extent of forest land increased from 16.5 million acres in 1977 to 16.7 million acres in 1990
- Aspen forests cover the largest percentage (35%) of forested lands in the state
- Reduced structural diversity of forest stands
- Projected wood harvests volume for the year 2000 are nearly double those of 1980

Major Policies and Programs

- Support for "no net loss of forests" (Minnesota Sustainable Forest Resources Act)
- Comprehensive timber harvesting and forest management guidelines
- White pine regeneration strategies
- Landscape-based forest resources planning and coordination
- Research, monitoring, and continuing education

BENEFITS of FORESTS

Forests are an integral part of our natural and cultural heritage. Minnesota forests range from the mixed conifer-hardwood forests in the north, to the broadleaf forests in the south, to the numerous parks and greenways in urban areas. All of these forested areas provide Minnesotans with a variety of essential goods and services (Figure 1).

Figure 1

Forest Ecosystem Benefits

Benefit Category	*Example*
Aesthetic	Beautiful scenery
Ecological	Microclimate regulation Erosion & flood control Maintenance of habitat & biodiversity
Economic	Timber products Non-timber products (e.g., maple syrup) Recreational tourism
Health	Clean air Water purification
Historic	Historic and cultural sites
Public use	Recreation (e.g., bird watching, hunting, fishing, camping)
Spiritual	Wilderness setting Bequest for future generations

Forest products are an important part of Minnesota's economy and provide wood for pulp, paper, and lumber. In 1995, the forest products industry (the third largest manufacturing industry in the state) contributed 7.8 billion dollars to the economy and provided 57,000 jobs (MDNR 1997). The state's forests also offer recreational benefits, providing hiking, camping, and hunting opportunities, and sites for education and scientific pursuits. These activities, in turn, bring substantial economic benefits to nearby communities. For example, most of the 1,300 privately owned resorts are closely associated with the pine and hardwood forests in the central region of the state (MFRC 1997a).

In addition to economic and recreational benefits, healthy forests provide numerous benefits that are often difficult to quantify (Jaakko Poyry 1992f). Aesthetic and spiritual forest values are of increasing importance to society (Bengston and Xy 1995), and forests provide essential ecosystem services (Johnson 1988; Rolston 1990). A variety of plants and animals depend on forests for habitat, including wildlife species of special concern such as the red-shouldered hawk, gray wolf, pine marten, wood turtle, and bald eagle (Leatherberry et al. 1995). Healthy forests maintain the light, temperature, and moisture conditions that support the animals and plants living there. Forests regulate overland and subsurface water flows, thus maintaining year-round water flows rather than flood-and-drought regimes. They contribute to healthy aquatic ecosystems by stabilizing streambanks and filtering sediment and nutrients from water moving through the forest. For example, in 1990 more than 200,000 acres of windbreaks and natural wooded strips helped prevent soil erosion and improve water quality (Leatherberry et al. 1995).

Forests also play a key role in cycling essential elements such as oxygen and carbon. We depend on forests and other plant communities for production of the oxygen that we breathe. They also trap carbon dioxide from the atmosphere and store it in leaves, trunks, and roots. Temperate forests worldwide may sequester about 0.7 billion tons of carbon annually, which would otherwise remain in the atmosphere and could contribute to global climate change (Dixon et al. 1994).

Minnesotans clearly depend on forests for a variety of important ecosystem goods and services. Such benefits are sustained only if we manage forests to promote their long-term health. Unhealthy forests cannot provide a full range of ecosystem benefits. By monitoring and tracking the health of Minnesota forests, we can better understand how to manage forests so that they continue to provide benefits that improve our daily quality of life.

FOREST ECOLOGY

General patterns in forest types

Minnesota has two major forest types: mixed conifer-hardwood forests and eastern broadleaf forests. The location of these forests and the differences in dominant species are determined by patterns in precipitation, temperature, underlying soils and landforms, and disturbance regimes (MDNR Ecological Classification System 1996, Figure 2).

Mixed conifer-hardwood forests occupy the north-central and northeast portion of the state. (Figure 2 refers to this area as the Laurentian Mixed Forest Province.) Soils have developed slowly in this region and are relatively nutrient poor. Forest types include coniferous upland species such as white pine, red pine, jack pine, balsam fir, and white spruce; hardwoods such as aspen, birch, and mixed oak; and lowland species such as black ash, black spruce, tamarack, and white cedar.

Eastern broadleaf forests occupy a transition zone between the mixed conifer-hardwood forests in the north and the agricultural land and tallgrass prairie in the south. A variety of deciduous forest types are associated with this transition zone. Maple-basswood forests are late-successional forests that occur in areas protected from fire. Oak forests occur most commonly in the southern and western edges of the transition zone. And some aspen forests occur in the northern regions, between extensive forested peatlands and grassland areas (MDNR Ecological Classification System 1996).

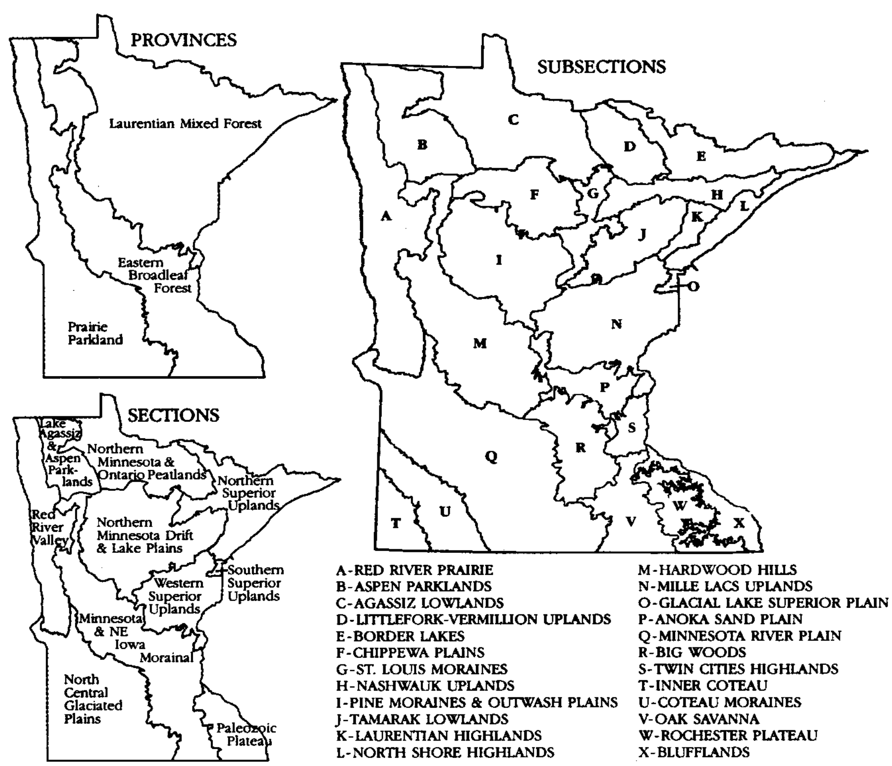
Knowledge about the extent and distribution of Minnesota's forests types is a basic step to understanding our forest resources. In other words, we need to know what kinds of forests occur across the state, how much area they cover, and where they are located. Indicators of the **extent and distribution of forest types** provide this baseline information about general patterns in Minnesota's forest ecosystems.

Diversity

In broad terms, biological diversity is the variety of life. It describes the number of ecosystem parts, how they are arranged, and the various processes that occur among them. Forest diversity has several levels of organization. **Landscape diversity** is the variation in forest types that occur within a large area (such as white pine, jack pine, and aspen forests). **Habitat diversity** is the variation in habitat characteristics occurring within a forest (such as the presence of dead trees that provide nesting cavities for wildlife). **Community diversity** is the number of different groups of plants and animals and how they interact (such as the associations among various plants, the animals that consume them, and the bacteria and fungi that decompose them). **Species diversity** is the variation in species occurring within a forest (such as the variety of plants and wildlife living within the fores). And **genetic diversity** is the variation in the gene

Figure 2

Ecological Classification System (ECS)



pool of forest species.
Forest diversity is influenced by a number of complex factors, including climatic condition; forest patch size, shape and configuration; continuity of forest stands; frequency and intensity of disturbance (fire, windthrow, pests); structural variability (tree age diversity, canopy openings, vertical layers); and human activities that alter these factors. For example, the diversity of forest types in a landscape depends in part on the continuity of forest stands and the pattern of fire regimes in that region.

Habitat and community diversity within a forest depend in part on changes in the structure of tree canopies. For example, the presence or absence of forest canopy openings influences the microclimate on the forest floor; this in turn affects plant species composition. Forests with dense canopy layers support understory plant species that tolerate low light. When disturbances (human and natural) occur that open up the canopy layer, more light reaches the forest floor, and other plant species that have higher light requirements begin to thrive. Thus, forested areas with occasional gaps created by fire, high wind, and some types of logging allow a diversity of plant communities to thrive at a stand level. Extensive gaps occurring throughout the forest, however, may be detrimental to biodiversity at a regional level (Jaakko Poyry 1992b).

Animal species diversity in forests depends in part on the physical structure of forest vegetation and the composition of plant species. Forests with several vertical layers (such as herbs, shrubs, trees of different ages and sizes, and downed logs) and spatial variability (such as canopy gaps and openings) provide a variety of habitat for wildlife species. For example, some song birds nest in vegetation near the ground, while others nest high in the canopy. Various mammals and birds live in the hollowed-out cavities of dead trees. And some mammals require forest openings for browse. Forestry practices that allow dead trees and downed logs to remain in place and that manage for stands with different-aged trees improve the quality and diversity of the available habitat (Jaakko Poyry 1992d).

When measuring and discussing forest diversity, it is essential to define the level of organization and spatial scale being addressed (Zumeta 1991). Indicators of diversity should span multiple levels. For example, the **extent and distribution of forest types** and the **proportion of forest in each age class** provide a broad measure of forest diversity at a landscape level. **Snag and woody debris density** and **foliage height diversity** provide some measures of habitat diversity. The **distribution and abundance of key plant species** (e.g., long-lived late-successional herbs) are indicators of community diversity. And the **ratio of "vulnerable" species to total "forest-dependent species"** is one way to assess changes in species diversity.

Biological productivity
Forest productivity includes the growth of plants via photosynthesis and the growth and reproduction of animals. Minnesota's deciduous forests are generally more productive than its northern coniferous forests (Tester 1995) due to a combination of warmer temperatures, higher precipitation, and more fertile soils. Tree growth in northern mixed conifer-hardwood forests is often limited by low soil fertility and the short growing season. Because soil productivity is the foundation for plant productivity in forests, management practices that promote healthy soils are essential for maintaining the productivity and sustainability of these systems (MFRC 1997c).

Disturbances that influence nutrient levels, available water, light on the forest floor, or temperature affect levels of productivity. These disturbances can be natural, such as fire or pests, or may be human-related events, such as clearing forest lands. Maintaining biological productivity in forests is important not only for numerous resource products (e.g., timber, pulpwood) but also for maintaining ecosystem functions (e.g., hydrologic cycles).

Indicators help assess the ability of a forest to maintain its productive capacity over time. Tree growth (e.g., **number, volume, and diameter of growing stock**) is one indicator of forest plant productivity. When coupled with indicators of harvesting trends, this indicator gives information about the ability of a forest to maintain the production of timber resources. **Population trends of key animal species** representing various trophic levels are an indicator of animal productivity. Indicators of animal productivity help assess trends across multiple trophic levels, which gives broader insight into overall forest health.

Nutrient cycling

Nutrient cycling is the movement of essential elements, such as nitrogen and carbon, through living and nonliving materials. Elements move from the atmosphere, through living plants, animals, and decomposers, and back to soil, water, and air.

Cycling within a forest is essential for continued growth and productivity. Plant growth and the subsequent breakdown of forest litter (dead leaves and other plant material) ensure that soils contain essential nutrients to support new generations of forest growth. Forest litter decomposition is caused by the activity of numerous organisms including birds, mammals, insects, worms, soil bacteria, and fungi, as well as physical processes such as wind and water erosion. Through this continual growth and breakdown of organic matter, healthy forests create soil, which is important for maintaining biological productivity within a forest (Leatherberry et al. 1995).

Forests play a crucial role in the cycling of elements among systems. For example, forests intercept and use nitrogen that is deposited from precipitation and erosion. When nitrogen is trapped by plant material, it remains in the forest system rather than being transported downslope to water bodies. This retention slows the introduction of nutrients into rivers, streams, lakes, and wetlands, and helps to maintain the quality of those systems. Activities that temporarily remove plant cover or disturb soils (e.g., timber harvesting) may increase erosion and nutrient loss to adjacent ecosystems. Best Management Practices (BMPs), which are widely used in Minnesota's forests today, reduce these impacts while maintaining the benefits of timber harvesting (Jaakko Poyry 1992g). However, activities that permanently remove forest cover (e.g., road construction, residential development) can greatly alter the cycling of nutrients within and through a landscape.

Forests also have a significant impact on nutrient cycling at a global scale. Trees use carbon dioxide from the atmosphere for new growth; thus, forests act as a storage area, or "sink," for carbon. This storage of carbon may offset some of the carbon released by increasing fuel emissions and thus diminish the effects of global climate change (Myers 1997).

Indicators of nutrient cycling are often difficult to measure but do provide important information about the health of a forest system. For example, the **percentage of land with significant soil erosion** provides information about how nutrients may be flowing out of forested systems into nearby water bodies. Other **physical changes in soils** (such as **thickness, compaction, bulk density**) give insights into the ability of a forest to maintain productivity. More specific measurements, such as the **area and percentage of forest where nutrient depletion exceeds replenishment (of potassium, calcium, magnesium)**, also give forest managers information about the ability of a forest to maintain productivity over time.

Hydrology

Forests play a key role in regulating overland and subsurface water flows within a watershed. They intercept rainfall and slow surface runoff, thus decreasing excessive and costly erosion. Forests slowly release captured water back to the atmosphere via evapotranspiration, and to streams and rivers within a watershed, thereby serving as a critical component in the hydrologic cycle and regulating the quantity and quality of water supply. Forested watersheds are more likely to provide a constant flow of clean water. In contrast, large deforested watersheds are more likely to experience flood-and-drought regimes, and water quality will likely be diminished due to erosion (Myers 1997).

At a more site-specific scale, the ability of forested areas to regulate water flow may be altered due to disturbances along vegetated waterways. The flow of water may change following the loss of riparian vegetation caused by natural events (e.g., fire) or human activities (e.g., harvesting).

Indicators that track **changes in stream flow** provide useful information about how well forests are maintaining hydrologic cycles within a watershed. It is especially important to compare these indicators to historic ranges of variability in stream flow. In managed areas the **area and percentage of stream miles with vegetated buffer strips** also gives insight into how well aquatic systems may be protected from the excess flow of nutrients from upland terrestrial systems.

Natural disturbance regimes

Disturbance regimes are recurring events that help maintain healthy ecosystems. While disturbances may sometimes seem temporarily catastrophic, over the long run they maintain natural cycles that are essential for healthy ecosystems. Important natural disturbances in forest ecosystems include fire, windthrow, insects and diseases, and animal grazing.

Differences in the frequency, intensity, and type of disturbance have shaped the composition of Minnesota's forests (Mladenoff and Pastor 1993). Before European settlement, areas in the transitional zone that were exposed to frequent fires from adjacent prairie were dominated by oak savanna, while forests in wetter areas near rivers and lakes were often dominated by lowland hardwoods. Areas protected from fire were characterized by old-growth "maple-basswood" forest, which was comprised mostly of elm and then basswood and maple (Grimm 1984). In northern forests, wildfire was a major factor determining species composition. Intense wildfires kill many species, but Minnesota's three pine species-red, white, and jack pine-are adapted to fire. Before European settlers arrived in the state, wildfires burned a pine forest every 13 to 38 years, with more intense fires every 150 to 200 years (Tester et al. 1997). These relatively frequent fires contributed to the dominance of fire-adapted pine trees.

Windstorms create gaps in the forest canopy in both conifer forests and deciduous forests. The gaps create spaces where more sunlight reaches the forest floor, allowing species that need more light to become established. In northern forests, windstorms often remove the older and taller red and white pines, leaving spruce, fir, maple trees, and young pines standing (Tester et al. 1997). Some kinds of timber harvesting can also create gaps in the forest and thus influence the amount of light reaching the forest floor.

Animal activities have significant impacts on the functioning and composition of the forest ecosystem. Beaver affect forest stands by removing trees and altering water flows. Herbivory by insects, such as the spruce budworm, and mammals, such as deer, affects the growth and reproduction of certain forest species. High deer populations strongly influence plant species composition in Minnesota's forests.

Humans can alter the frequency and intensity of some natural disturbances in forests by preventing forest fires, harvesting timber, and influencing population numbers of browsers such as deer. Some disturbances, including the introduction of exotic species and broad changes in landscape patterns, are very different from the disturbances that historically shaped forests because they typically involve faster changes, are of greater intensity, and affect larger areas than do natural disturbances. Extreme changes in natural disturbance regimes can have detrimental effects on the health of Minnesota's forests. Humans also help restore natural cycles that have been altered over time. For example, forest managers may implement prescribed burns or use harvesting techniques that strive to mimic disturbance cycles. Such efforts to work with nature's cycles help maintain healthy forests. Mimicking natural spatial patterns and disturbances is one of the most effective ways to conserve forest diversity (Jaakko Poyry 1992b).

Knowledge about the historic range of variation is important to interpret indicators of disturbance cycles. For example, **acres of forest burned annually** is an important indicator that gauges the extent and frequency of forest fires. This indicator is especially important in coniferous forests, where some forest types require fires for regeneration and renewal (e.g., jack pine). Knowing the historic range of variation for fire in jack pine forests helps interpret this indicator so that managers can develop appropriate fire management plans. The **frequency of pest and disease outbreaks** is another indicator of disturbance cycles that provides information about how forest health may be changing over time.

PRESSURES ON FORESTS

Land conversion

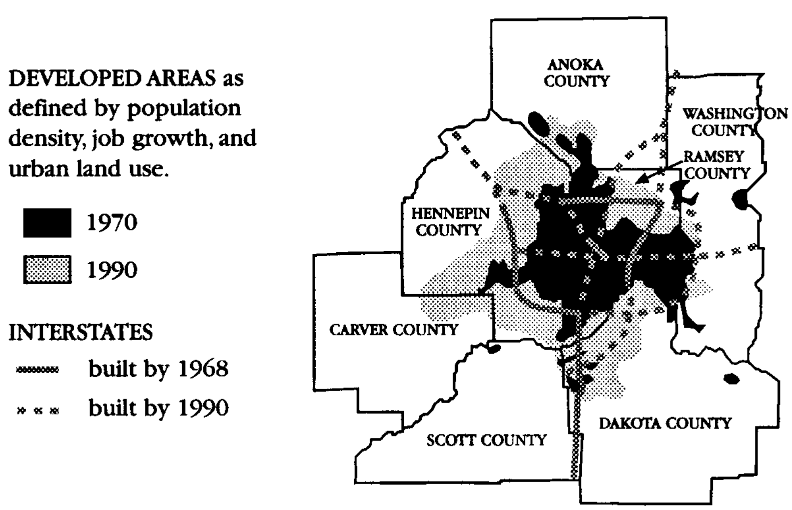
The largest changes in Minnesota's forests over the past 150 years have resulted from clearing land for settlement, agriculture, and harvesting timber (Ahlgren and Ahlgren 1983). During the late 1800s and early 1900s, much of the state's forests were cleared for settlement and farming. Timber harvesting of valuable trees also contributed to a loss of forest land. Following white pine harvests in the late 1800s and early 1900s, much of the land was not replanted or managed; rather, it was left for settlement and farming (White Pine Regeneration Strategies Work Group 1996). While dramatic changes following European settlement reduced Minnesota's forest extent by approximately 20 million acres (Leatherberry et al. 1995), regrowth and changes in management practices have resulted in an increase statewide from 12 million acres in 1900 to 17 million acres today (MDNR 1997).

Today's loss of forested land is greatly affected by development patterns. Currently urban development, including transportation corridors, accounts for most of the loss and fragmentation of forest in the prairie-forest transition region (TNC 1995), particularly around the Twin Cities metropolitan area (MDNR 1995; Figure 3). In the northern lakes region, lakeshore development is a cause of loss and fragmentation of forests.

Indicators that track land use and conversion provide some of the most basic assessments of ecosystem status and trends. For example, the **percentage of forest land area converted to other uses** is particularly relevant considering the growing desire for "no net loss" of forested land (1995 Minnesota Sustainable Forest Resources Act). When coupled with indicators of ecosystem functions, such as hydrology, these indicators give insight into how land conversion may be affecting flood and drought regimes in a watershed.

Figure 3

Twin Cities Metro Area Urban Development



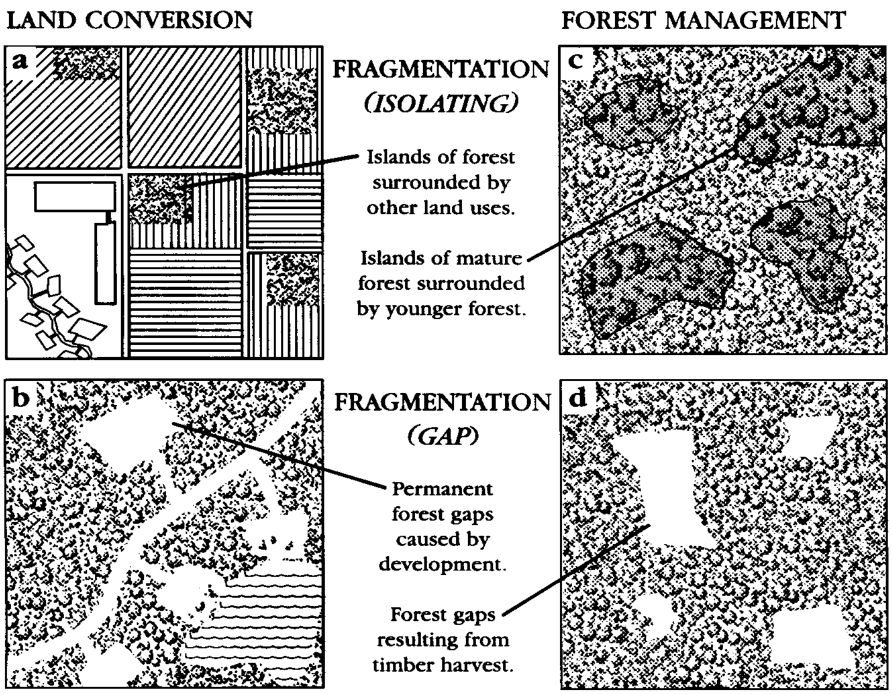
Source: Star Tribune, Sunday, April 16, 1995

Fragmentation

Forest fragmentation is simply defined as the disruption in the continuity of a forest habitat (Lord and Norton 1990). Within this broad definition, various types of fragmentation can be distinguished (Harris and Silva-Lopez 1992; Figure 4). Relatively permanent fragmentation, such as that created by development and land conversion (Figure 4a, b), differs from more temporary types, caused by timber harvest and land management (Figure 4c, d; Jaakko Poyry 1992b). Fragmentation also occurs in different spatial forms. "Isolating" fragmentation reduces the existing forest to small patches surrounded by another land use (e.g., small forest patches surrounded by agriculture [Figure 4a]) or another age class (e.g., old-growth patches surrounded by younger forests [Figure 4c]). "Gap" fragmentation is less extensive and creates gaps within continuous forest cover (e.g., openings for lake homes [Fig. 4b], or patches of clear-cut in a continuous forest [Figure 4d]).

Forest fragmentation can significantly alter ecological functions in some forested landscapes (Jaakko Poyry 1992b). Relatively permanent, isolating fragmentation caused by agriculture and extensive development (Figure 4a) can

Figure 4
Examples of Forest Fragmentation



profoundly affect the landscape by altering microclimate, water flows, nutrient cycling, and forest patch regeneration. It also has detrimental effects on animal and plant species that require large patches of forested land for survival and reproduction. Small patches of forest have more edge habitat relative to interior forest habitat than do large patches of forest. This situation creates conditions that hinder some native plants and animals in favor of disturbance-tolerant species. For example, smaller forest fragments favor common species, like the brown-headed cowbird and the blue jay, at the expense of birds preferring interior forest conditions, like the ovenbird (Table 1).

Isolating fragmentation caused by widespread timber harvest can also have an impact on forest composition and function. For example, old-growth pine stands once covered a larger portion of Minnesota's landscape, but many remaining pine stands are now separated, or fragmented, by other forest types. This condition may affect mature-forest dependent species that require certain types of habitat, such as the pine warbler, which requires a minimum patch size of 25 acres of mature pine (Green 1995).

The effects of gap fragmentation, however, are not well understood. Forest gaps caused by certain silvicultural techniques can be similar to natural disturbances such as windthrows, and are beneficial to wildlife species that prefer young forest patches. Many forest harvests have been designated for this very reason. At a local scale these gaps may be desireable because they enhance or create habitat for important gamebird and other animal species. When considered at a larger scale, however, the implications may differ (Jaakko Poyry 1992b). For example, gaps caused by harvesting may be of a different size or frequency than the openings historically created by windthrow or fire. Like other forms of fragmentation, clear-cut gaps will increase "edge" habitat and reduce the overall extent of mature forest, which may have a negative effect on some area-sensitive bird species (Manolis et al. in review). Ongoing research should help increase understanding of how gap fragmentation affects the diversity and functions of forested systems.

Indicators can also play an important role in better understanding forest fragmentation. Indicators such as the **ratio of forest interior to total forest area** provide measures of fragmentation. Also, mapping the **distribution of forested areas in the landscape** is particularly useful for tracking trends in forest fragmentation. When coupled with indicators that track key ecosystem properties (such as songbird population trends), these indicators give insight into how forest fragmentation may be affecting forest functions over time.

Table 1
Bird Species Sensitive to Forest Fragmentation

Red Shouldered Hawk
Barred Owl
American Redstart
Red-eyed Vireo
Yellow Throated Vireo
Pileated Woodpecker
Acadian Flycatcher
Northern Waterthrush
Louisiana Waterthrush
Northern Parula
Black-and-white Warbler
Hooded Warbler
Black-throated-blue Warbler
Cerulean Warbler
Canada Warbler
Ovenbird
Scarlet Tanager

Source: Jaakko Poyry 1992d

Timber harvesting

Tree removal can affect forest structure and function at local sites or across large regions depending on the intensity and frequency of harvesting methods. For example, logging may affect forest soil resources by removing nutrients from the site and compacting and eroding soils; the magnitude of this impact varies with soil type, tree species, and time between harvest (MEQB et al. 1993).

In general, activities such as road construction, skidding practices, and yarding (log storage) have the greatest potential to cause soil compaction and erosion, which in turn may diminish long-term forest productivity (Government of Canada 1991). In addition, removal of vegetation along water bodies increases the potential for erosion and flooding.

Thus, timber harvesting in riparian areas can have impacts on the water quality of adjacent streams and rivers, many of which support important recreational fish species, such as trout and bass. Timber harvesting also has the potential to affect forest habitat and wildlife. Changes in the composition and structure of a forest influence the diversity and distribution of wildlife species. They may also influence the degree and intensity to which pest or disease outbreaks occur (MEQB et al. 1993).

At a landscape scale, harvesting may perpetuate forests that are compositionally and structurally simplified because stands of short-lived species, usually in pure cultures, are readily used by the pulpwood industry (Kotar 1997).

Forest managers use a variety of practices to mitigate adverse effects of timber harvesting (Jaakko Poyry 1992a). Compliance with Best Management Practices maintains the quality of nearby water bodies and dependent fish communities (Jaakko Poyry 1992g). Nutrient loss, soil compaction, and soil erosion can be lessened by keeping as much organic material as possible on site, timing the harvest during winter or dry periods, and considering soil type and topography (MEQB et al. 1993).

Managers can mimic natural disturbance regimes by matching the appropriate silvicultural system to a given forest area (e.g., creating gaps from harvesting that are similar to those historically caused by windthrow or fires). A variety of silvicultural and management practices also help restore forest types that are currently difficult to regenerate naturally, such as red oak and white pine (Kotar 1997; Jaakko Poyry 1992e). These approaches help ensure the maintenance of diverse forest conditions and functions.

In recent years timber certification programs have developed to identify and promote the use of timber from well-managed sources. For example, in 1997 more than 555,000 acres of forest land in Aitkin County were certified as being sustainably managed by the Smartwood Program (MOEA 1998).

Indicators that track **harvesting trends** and **application of silvicultural practices** provide baseline information on possible impacts to forested areas. The **actual and projected timber harvest by species** (million cords/ year) gives general information about demands on forest resources. Indicators like the **percentage of forest land area lost to forest harvest infrastructure** (e.g., roads and trails for large equipment) also track pressures on forested areas. Coupling indicators that measure harvesting trends and ecological functions (e.g., soil productivity) provides insight into how harvesting may affect long-term forest health. Efforts to understand such relationships were part of the task of Minnesota's Generic Environmental Impact Statement on Timber Harvesting and Forest Management

(GEIS) (Jaakko Poyry 1992a).

Recreational activities

The increase in the number of vacation and second homes in and around Minnesota's forests has resulted in forest land conversion and fragmentation and increased recreational demands in forested areas. New homes, roads, and supporting commercial facilities fragment the forest and increase the potential for non-native or disturbance-tolerant species to move into the forest. In addition, management decisions for forests become more socially and ecologically complex. For example, fire is important for maintaining the long-term health of mixed conifer-hardwood forests. However, increasing numbers of people living or recreating in these forests make it more difficult to allow natural fires to burn, or to implement prescribed burn regimes.

In recent years, use of off-highway vehicles (OHVs) in Minnesota's forests has increased. As OHVs are used to access larger and more remote areas, there are increased concerns that this activity may augment soil compaction and erosion, harm understory shrubs and herbs, and disturb animal populations that depend on large, contiguous forests. Plans that will manage use of OHVs to sustain forest health while allowing desired human use are currently under consideration by stakeholder forums. Finally, increased use of wilderness area forests for motorized and nonmotorized activities has resulted in conflicting opinions about land use and management needs, a situation that further illustrates the complex trade-offs that forest managers must address.

A variety of tools are necessary to help manage the complexities involved with forest lands and recreation. The Recreation Opportunity Spectrum (ROS) is one tool that sets standards for forest conditions and classifies forest lands according to the kinds of recreational experiences that people want to enjoy. For example, urban forests provide parks and resort areas, semi-primitive motorized forest lands provide a predominantly natural-appearing environment while still allowing for motorized recreation, and primitive areas allow for a greater wilderness experience (USFS 1990). Maintaining a full spectrum of forest lands ensures that Minnesotans have access to a variety of recreational opportunities (MSDI 1994).

Indicators that track **trends in recreational demands and activities on forested areas** (such as OHV use and other trail use) provide information about where and how these activities may affect forest ecosystems. It is important to link these indicators to trends in ecological properties (such as **soil compaction, plant community composition**, and **distribution of wildlife species**) to better understand to what degree these recreational activities may affect the health of forested systems. This information is useful in developing recreational management plans for Minnesota's forests. Recreational benefits are appreciated by Minnesota's citizens; managing for healthy forests helps ensure that these benefits will be maintained for the long term.

Biological pressures

Biological pressures on forest ecosystems include exotic species, pests, diseases, and grazers. Exotic species compete with native forest species and may eliminate important food and nesting resources. For example, the Tatarian honeysuckle and European buckthorn were introduced as ornamental shrubs and hedges but have spread uncontrollably and now dominate the understory in many forests at the expense of native species that are important animal food and habitat (TNC 1995).

Pests and diseases occur in all forests; they are natural change agents and play an important part in forest food webs and forest succession (Mladenoff and Pastor 1993). At high levels or unnatural frequencies, however, they can disrupt forest functions. Pests in Minnesota's forests include the forest tent caterpillar, spruce budworm, white pine weevil, two-lined chestnut borer, and the gypsy moth. Diseases include trunk rot, white pine blister rust, Dutch elm disease, and oak wilt (Jaakko Poyry 1992c; MDNR 1995a).

In many cases the worst pests and diseases are those that are introduced from Europe and Asia. For example, Dutch elm disease, white pine blister rust, and gypsy moths are introductions that in some cases have significantly altered forest functions in this region (Mielke 1997). Pests and diseases decrease forest productivity by reducing growth rates and increasing incidences of mortality and decay. Monocultures or trees that are under stress due to other reasons, such as pollution or drought, are most susceptible to attack (Mielke 1997). A variety of management practices are used to reduce the impacts of these biological pressures on Minnesota's forests (Jaakko Poyry 1992c).

Browsers, such as deer, also place pressure on some forests by limiting regeneration of certain kinds of trees, such as white pine. Minnesota's white-tailed deer populations once occurred mostly in wooded transitional areas, and occurred in larger numbers in northern forests only after timber harvesting and clearings created ideal browse habitat (White Pine Regeneration Strategies Work Group 1996). While deer are an important game species and an integral part of Minnesota's forests, they now occur at a much greater density than they did historically, and thus exert a new kind of pressure on our forests.

Human activities indirectly alter the frequency and intensity of biological pressures. In some situations, biological pressures that historically played a role in disturbance cycles have now become more extreme and threaten the long-term health of forest ecosystems. For example, pest populations play a natural role in forested systems (Mladenoff and Pastor 1993). At low levels, pests, such as spruce budworm, may not cause problems because their populations are limited by natural factors, such as forest songbirds that consume them. Thus, human activities that reduce forest songbird populations, such as fragmentation and deforestation in tropical breeding grounds, can indirectly increase a pest's population. Understanding the complex relationships between human activities and biological pressures is a challenging but important task.

Monitoring **trends in exotic species, pests, diseases**, and **population trends of important browsers** (e.g., deer) gives forest managers early warning about potential changes in forest productivity and overall forest health. Linking population trends of pests (e.g., forest tent caterpillar) to **tree mortality** (e.g., in aspen) may illustrate how biological pressures can affect long-term productivity. If long-term data are available, these indicators show whether biological pressures are occurring more frequently and intensely than their historic cycles. This information may provide early warnings of negative changes in Minnesota's forests and is essential for identifying preventive strategies to maintain healthy forests.

Atmospheric pollutants

Several kinds of atmospheric pollutants can have wide-ranging impacts on forest systems. Acid precipitation is not currently a major problem in Minnesota but has caused extensive degradation of eastern forests. Ozone, a primary component of smog, causes direct physical damage to trees. Global increases in fixed nitrogen from fossil fuels and agricultural fertilizers result in chronic nitrogen deposition and may have long-term implications for forest health (Foster et al. 1997).

Increases in greenhouse gases such as carbon dioxide will likely cause warmer temperatures, influence precipitation patterns, and may reduce soil moisture (MEQB et al. 1993). These changes in global climate patterns are likely to alter growing conditions (Stearns 1987) and the range and distribution of forest species (Government of Canada 1991). For example, some scientists who have researched the implications of climate change for Minnesota believe that many forested areas will not be able to sustain rapid climate changes; rather, over time vegetation patterns will shift in a northeastward direction, and current forests may convert to brush and grasslands (reported by Dawson and Marcotty 1997).

Monitoring **trends in airborne pollutants and greenhouse gases** provides necessary baseline information about changes in the atmosphere. Forest indicators can illustrate how these pressures may be affecting the long-term health of terrestrial systems. For example, **trends in sensitive species** (e.g., mosses and lichens) indicate the degree to which airborne pollutants may be affecting forested areas and may serve as an early warning to forest managers.

FOREST STATUS AND TRENDS

Minnesota's landscape before European settlement

Before European settlement, forests covered about 60% of the land area in Minnesota (Leatherberry et al. 1995). Forests were most extensive in the northern and south-central regions of the state; the southwestern region of the state was dominated by prairies. The mixed conifer-hardwoods in the northern region of the state included a mosaic of pine forests, extensive conifer bogs, and upland hardwoods (Stearns 1987). The central transitional region of the state included a patchwork of eastern broadleaf forests, prairie, savanna, and wetlands. The south-central region of the state was dominated by the "Big Woods" maple-basswood forest, and the southeastern region was dominated by oak forest (Leatherberry et al. 1995).

Changes following European settlement

The extent and character of Minnesota's forests have undergone many changes since European settlement (Table 2). During the late 1800s and early 1900s, many of Minnesota's forests were cleared for various purposes. Mature pine trees provided a rich resource for Minnesota's lumbering industry, which reached its peak in production in 1905. In addition, forests across the state were rapidly cleared for agriculture and settlement (Stearns 1987). The U.S. Land Office Surveys recorded that the total land area of Minnesota's forests decreased dramatically from 31.5 million acres in 1850 to a historical low of 11.9 million acres in 1895 (Leatherberry et al. 1995).

The composition of Minnesota's forests also changed following European settlement. In particular, areas that were once pine forests converted to aspen or shade-tolerant species such as spruce and fir (Ahlgren and Ahlgren 1983). Forests that were dominated by white and red pines that once occupied about 3.5 million acres before European settlement now occupy only about 0.5 million acres, and most are second-growth (Frelich 1995).

Logging, fire suppression, and biological pressures from deer and diseases caused most of these changes in the composition of Minnesota's forests (White Pine Regeneration Strategies Work Group 1996). Before European settlement, areas occupied by white and red pine forests were maintained by a natural disturbance regime; periodic fires killed invading hardwoods and shade-tolerant species while allowing mature pines to survive. Variability in the frequency and intensity of fires resulted in a shifting mosaic of pines interspersed with other conifer and hardwood species. With intensive logging at the turn of the century, however, vast numbers of pine trees were removed from the landscape. A lack of seed sources combined with destructive postlogging fires inhibited the return of these pine forests (Ahlgren and Ahlgren 1983). Since then, suppression of low and moderate intensity fires has limited the ability of the remaining pines to outcompete and survive other invading species. Increased deer populations also have exerted significant pressures on pines because deer browse on seedlings, which can prevent reestablishment of pine stands at many locations. In addition, white pine blister rust contributes to the difficulty of maintaining and regenerating white pine stands (White

Table 2

Forest Changes Following European Settlement

Forest Characteristic Change	*Example*
Area	Reduction in extent
Age structure	Loss of old growth, homogenization of stand age
Species composition	Pine forests converted to aspen spruce-fir
Landscape spatial pattern	Greater fragmentation
Disturbance intervals	Extensive wildfires, then fire suppression

Compiled from Frelich 1992, Mladenoff and Pastor 1993

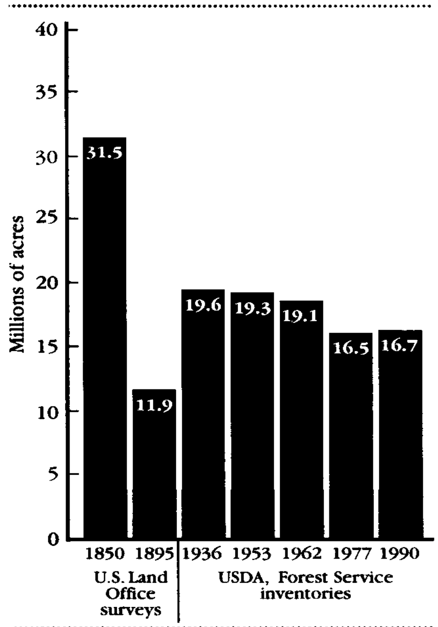
Pine Regeneration Strategies Work Group 1996). The changes in the character and composition of northern forests over the past century illustrate how biological factors and human activities can intermingle to dramatically alter a landscape.

Extent of today's forests

Regrowth of trees and forest management efforts including protection, reforestation, and conservation helped forests expand their total land area since the turn of the century (Figure 5). The Forest Resource Inventory recorded 16.7 million acres of forest in 1990 (Leatherberry et al. 1995), with the majority of forested area occurring in the northern region of the state (Figure 6). The number and volume of growing stock trees has increased as well; inventories between 1977 and 1990 showed a 10% increase in number and a 22% increase in volume (Leatherberry et al. 1995). Today a number of land-use factors affect the extent of Minnesota's forests. While forests cover much of the northern part of the state, forests in the south and central regions are patchy and heavily fragmented (Figure 7). Large areas once covered by eastern-broadleaf forest were permanently converted to agricultural or developed areas throughout the past century (Figure 8). The maple-basswood forest of the Big Woods once covered 3,420 square miles in south-central Minnesota; today it covers a few thousand acres and includes only a few hundreds acres of old-growth forest (Rusterholz 1990). Other ecosystem types were permanently converted as well; for example, less than 0.1% of pre-European settlement oak savanna remains in south-central Minnesota (MDNR 1996).

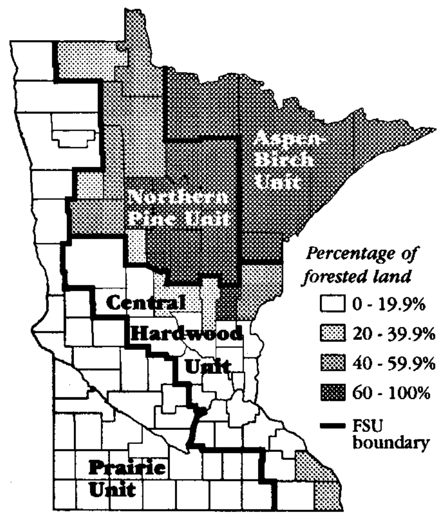
In recent years, however, the Forest Resource Inventory reports that the number of forest land acres has remained more stable. For example, in the Central Hardwood Unit the percentage of forested land area has slightly increased since the 1977 Forest Resource Inventory (Table 3); conversion to agriculture has decreased, and efforts at tree regeneration have increased. Programs that take highly erodible lands out of agricultural production and regenerate trees help maintain these forested areas (Leatherberry et al. 1995). But in many areas, such as the Big Woods, loss of forested land to agriculture is being replaced by loss to urban growth. Encroaching development is now the greatest threat to the extent of many forested areas (Big Woods Project n.d.; TNC 1995).

Figure 5
Number of Forested Acres in Minnesota 1850-1990



Source: Leatherby et al. 1995

Figure 6
Percentage of Cover in Forest Survey Units, 1990



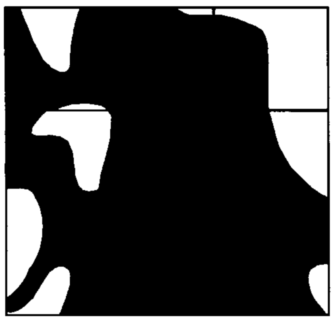
Source: Leatherby et al. 1995

Composition, structure, and function of today's forests

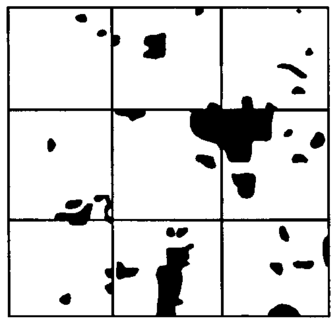
Increases in forest acres during the twentieth century have increased benefits such as erosion control, habitat for certain kinds of wildlife, nutrient uptake, removal of atmospheric pollutants, and continued production of timber resources. Regrown forested acres can be quite different, however, in composition, structure, and function; in many cases they are not comparable to presettlement forests in terms of forest type, age class, and

Figure 7
Changes in Forest Cover, Big Woods Area

Forested Areas, 1850s



Forested Areas, 1991



Presettlement forests in Erin Township, Rice County, MN (left), adapted from the Public Land Survey 1847 - 1907.

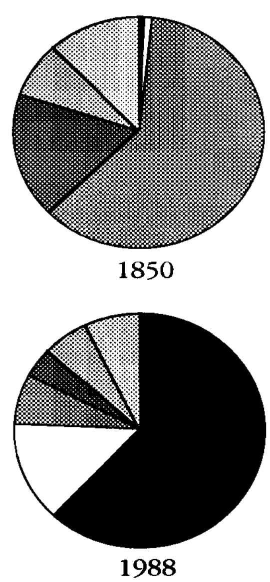
1991 forested areas in Erin Township, Rice County, MN (right) adapted from aerial photographs by Laura Jahnke and Jen Thurk.

overall biodiversity. For example, large areas of pine forests have been replaced by boreal conifer-hardwood forests composed largely of aspen (Figure 9).

Aspen accounts for 35% of the state's timberland area. Lowland conifer types, such as black spruce, northern white cedar, and tamarack, make up 18% of the state's timberland. Many of these forests occur in the extensive bog areas of northern Minnesota. In the transitional region of the state other hardwoods make up significant portions of the forested landscape. The 1990 Forest Resource Inventory shows that oak-hickory, maple-basswood, and elm-ash-maple forests occur frequently in the forested landscape of the Central Hardwood Unit, and have slightly increased since the last inventory (Leatherberry et al. 1995).
In addition to changes in composition, many of Minnesota's forests have undergone significant age-class and structural changes (Stearns 1987). In 1990 the median age of the state's timberlands was 50 years (Figure 10). Young, early-successional hardwoods occur frequently throughout today's forests along with maturing even-aged stands. Many of these are single-age aspen stands. Frequently these stands have less structural diversity compared to older forests; for example, there are fewer snags and downed logs, which provide habitat for wildlife. Old-growth forests that support greater structural diversity are now much less common. About half of the forest before European settlement was old growth. In northern forests, only 1.6% of pre-European settlement old-growth pine forests remain (Tester et al. 1997).

In general, reductions in forest acreage, changes in species composition from presettlement landscapes, and shifts in forest age structure have reduced the biological diversity of Minnesota's forests (Jaakko Poyry 1992a). This reduction of biodiversity may occur at different scales, ranging from landscape diversity to species diversity. Today hardwood forests are the primary habitat for 51 of the state's 287 plant and animal species that are now listed as endangered,

Figure 8
Land Cover in the Big Woods Landscape



	1850	*1988*
Agriculture	<1%	62%
Urban	<1%	13.9%
Forest	62%	6.9%
Shrub/Savanna	18%	4.1%
Water	8%	6.2%
Wetland	12%	6.9%

From *Metro Region Forest Resources Management Plan*, 1995. Estimates based on original land survey notes.

Source: MDNR 1995a

Table 3

Total Forest Land Area in the Central Hardwood Unit

	All forested land area (millions of acres)	Percentage forested land
1962	2.75	22.9%
1977	2.14	18.0%
1990	2.26	19.7%

Source: Leatherby et al. 1995

threatened, or of special concern (Pfannmuller and Coffin 1989). In recent years, management practices that target two of these species, bald eagles and timber wolves, have resulted in significant increases in their populations. Because forests with a greater variety of species and habitats are generally thought to be better able to tolerate and recover from a disturbance, achieving similar successes with other rare and endangered plants and animals is an important challenge for today's forest managers. Yet, a species-by-species approach is ecologically and economically impractical over the long term; thus, managers are challenged to consider holistic approaches to maintaining the overall integrity and diversity of forested systems (Jaakko Poyry 1992b).

Current trends and practices

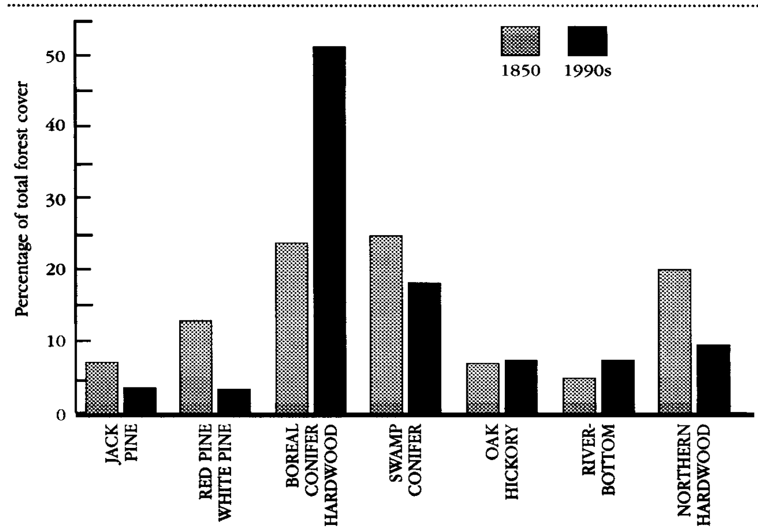
Harvesting

Demand for forest products continues to increase, and wood harvest in Minnesota is expected to increase into the year 2000 (Figure 11). Minnesota's wood harvest will continue to be dominated by aspen, followed by species harvested at much lower levels, such as pine, balsam, fir, spruce, birch, and oak. However, the GEIS predicts that aspen harvest will decrease in 10 to 15 years, and that the harvest of other hardwoods will increase. Minnesota's timber harvest is mostly used for pulp and paper (35%), waferboard and oriented strand board (32%), and lumber (16%) (MDNR 1997).

Forest managers use a variety of approaches to maintain and restore healthy forests and mitigate adverse effects of harvesting. Landscape-level plans help managers develop harvest rotations that take into account broader spatial and time scales, thus promoting the long-term health of the forested landscape. Such landscape-level efforts are not intended to reestablish the exact presettlement pattern of forest vegetation, but they may help include some of the structural and compositional elements that were lost following extensive lumbering at the turn of the century (Kotar 1997). At the site level, harvesting techniques that follow Best Management Practices (BMPs) help protect water quality in lakes and streams. Forest Resource Council technical teams are developing more comprehensive forest management guidelines to address critical areas such as forest soil productivity, riparian management, wildlife habitat, and cultural and historical resources (MFRC 1997a). In addition,

Figure 9

Comparison of Pre-European Settlement and Current Forest Area

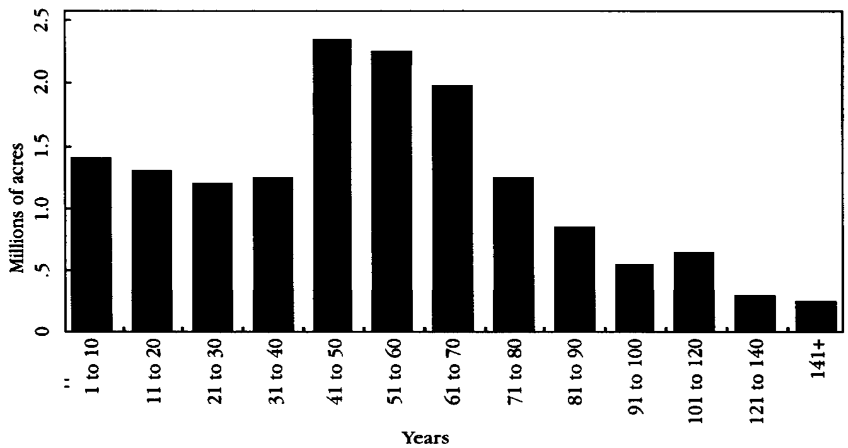


Note: Boreal conifer hardwood includes aspen, birch, and spruce. Northern hardwood includes maple and basswood.

Source: Jaakko Poyry 1992b, based on original land survey notes.

Figure 10

Age of Timberlands as of 1990



Source: Leatherby et al. 1995

programs such as the Forest Stewardship Program help landowners meet individualized goals and needs while at the same time using guidelines to ensure sound harvesting techniques. Programs that focus on planting and regeneration also strive to ensure long-term forest productivity.

Although these approaches are intended to mitigate potentially adverse effects of harvesting and to maintain the long-term health of Minnesota's forests, to what degree these practices are implemented and how effective they are at protecting Minnesota's forest resources is not always clear. Thus, it is important to devise monitoring strategies that evaluate the success of these programs. The Minnesota Forest Resource Council is currently developing compliance and effectiveness monitoring to track how well various mitigation strategies are protecting the long-term health of Minnesota's forests (MFRC 1997a).

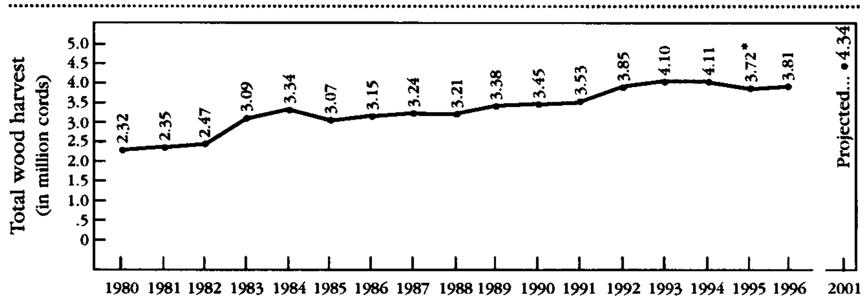
Ownership

Statewide, almost 50% of forest land is in private ownership (Miles et al. 1995). In some areas of the state, however, a greater percentage of the forest is privately owned; 80% of the forested land in the Central Hardwood Unit is owned by farmers, corporations, and individuals, with farmers holding the majority of the land (Figure 12). These patterns have significant implications for forest management and monitoring because of the need to work cooperatively across ownership boundaries.

Traditionally, forest harvest management has been applied on a stand-by-stand basis (stands are 1-50 acres), with only one owner involved in management decisions. But at this small scale, it is difficult to conserve biological diversity and provide recreational opportunities while accommodating production needs. Today management decisions are increasingly based at the larger, landscape scale (100s to 1,000s acres) and require the cooperation of numerous agencies, stakeholders, and landowners (MDNR 1997; Workshop Summary 1996).

Figure 11

Total Wood Harvest from Minnesota Timberlands

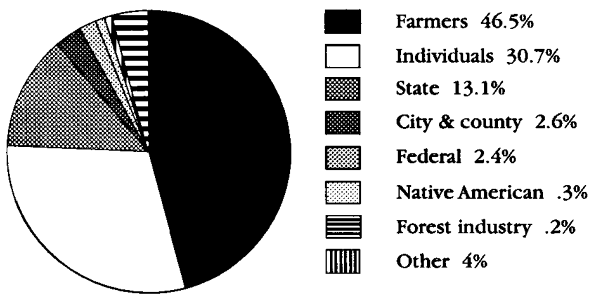


*Adjustment due to decrease in fuelwood use since 1989-90

Source: MDNR 1995b, 1997

Figure 12

1990 Ownership Pattern of Forest Land Area in the Central Hardwood Unit



Source: Leatherby et al. 1995

EXISTING POLICIES AND PROGRAMS

The 1995 Minnesota Sustainable Forest Resources Act (SFRA) fosters "no net loss" of forests and the maintenance of forest diversity with new policies and programs that encourage sustained management, use, and protection of the state's forest resources (MFRC 1997b). The SFRA legislation culminated a process during which diverse stakeholders worked together to learn about Minnesota's forest resources and to make wide-ranging forest policy recommendations. The Generic Environmental Impact Statement on Timber Harvesting and Forest Management (GEIS) was a major part of this process; it examined the status of timber harvesting in Minnesota, assessed potential impacts associated with different levels of harvest, and developed mitigation strategies. Following the GEIS, representatives of different stakeholder groups worked to reach consensus on implementation strategies. Now, the Minnesota Forest Resources Council (MFRC), created from the 1995 SFRA legislation, will use what was learned from this process to develop forest policies and facilitate their implementation. In addition, the MFRC will help integrate the numerous policies and programs that currently exist in Minnesota. Key areas of focus include (MFRC 1997a):

Site- and landscape-level planning.

Efforts to manage across political and ecological boundaries are critical to sustaining healthy forests. The MFRC will provide landowners with site-level assistance through the development of voluntary timber harvesting and forest management guidelines that focus on forest riparian zones, wildlife, soil productivity, and historical and cultural resources. In addition, the MFRC is developing a landscape-based planning process to better integrate site- and landscape-level objectives into broader regional forest resource goals.

Continuing education and outreach.

The MFRC encourages education programs to keep Minnesota citizens informed about forest issues. For example, the Minnesota Logger Education Program and the Center for Continuing Education of Natural Resources Professionals help forest professionals stay up to date on the latest scientific information, technologies, and issues.

Improved coordination and collaboration.

The MFRC represents a range of forest interests in Minnesota. The MFRC also recognizes and works with existing programs that implement forest policy and management. For example, the USDA Forest Service revises National Forest Plans every 10 to 15 years in accordance with the National Forest Management Act (NFMA) of 1976, the American Forest and Paper Association promotes sustainable forestry principles through its Sustainable Forestry Initiative, and the DNR Old-Growth Forest Identification and Protection Guidelines provide policy direction while landscape-level planning is under development.

Research and monitoring.

Managing for healthy forests requires timely scientific information. In addition to promoting basic research and the availability of forest resource information, the MFRC calls for three types of monitoring: "1) forest resource monitoring, to assess broad trends and conditions in forests resources at statewide, landscape and site levels; 2) practices and compliance monitoring, to monitor the actual use of certain timber harvesting and forest management practices; and 3) effectiveness monitoring, to provide information on the ability of various timber harvesting and forest management mitigation practices to achieve their intended objectives" (MFRC 1997a). The EII and MFRC are working to develop a comprehensive set of indicators for Minnesota's forest ecosystems.

EXAMPLE INDICATORS

Table 4 collects the indicators used in this chapter. The indicators are organized within the EII framework, which helps illustrate relationships among human activities, environmental condition, the flow of benefits from the environment, and strategies for sustaining a healthy environment. The indicators used in the chapter are examples that illustrate how indicators may help assess the condition of Minnesota's forests. The process of developing a comprehensive set of indicators that assess forest condition is ongoing. Developing indicators will require collaboration with stakeholders interested in their use, testing, refinement, and standardization of measurement techniques.

Table 4
Example Indicators

HUMAN ACTIVITIES	ENVIRONMENTAL CONDITION	SOCIETAL STRATEGIES
Land conversion • Percentage of forest land area converted to other uses **Fragmentation** • Ratio of forest interior to total forest area • Distribution of forested land area across the landscape **Harvesting** • Actual and projected timber harvested by species (cords/year) • Percentage of forest land area lost to forest harvest infrastructure (e.g., roads) **Recreation** • Trends in recreational use in forested land areas (OHV and other trail use) **Biological Pressures** • Trends in exotic species, pests, diseases (buckthorn, spruce budworm, gypsy moth, blister rust) • Population trends of important grazers (deer) **Atmospheric Pollutants** • Trends in sensitive species (mosses/lichens)	**Diversity** • Extent and distribution of forest types • Snag and woody debris density • Distribution and abundance of key plant species • Ratio of 'vulnerable species' to total 'forest dependent species' **Productivity** • Tree growth (number, volume, diameter of growing stock) • Population trends of key animal species from various trophic levels **Cycling** • Area and percentage of land with significant soil erosion • Physical changes in soil (thickness, compaction, density) • Percentage of sites where nutrient depletion exceeds replenishment (potassium, calcium, magnesium) **Hydrology** • Percentage of stream miles where flow and timing significantly exceed historic range of variation • Percentage of stream miles with vegetated buffer strips **Natural Disturbance** • Acres of fire burned annually • Pest/disease outbreak frequency	**Forest Planning & Management** • Development and implementation of forest management guidelines targeting riparian management, site-level wildlife habitat, soil productivity, and historical and cultural resources • Landscape-based forest resource planning and coordination • Regeneration strategies (e.g., white pine, oak) • Forest resource, compliance, and effectiveness monitoring **Research & Education** • Research on priority issues • Outreach and continuing education **Policy & Legislative Mandates** • 1995 Minnesota Sustainable Forest Resources Act (SFRA) for sustained management, use, and protection of the state's forest resources. No net loss of forests and maintenance of forest diversity.

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