3 MINNESOTA'S FOREST RESOURCES

3.1 Forest Resources

As used in this study, the term *forest resources* refers broadly to the range of values and outputs, both consumptive and nonconsumptive, commonly associated with forested environments. Such values include wildlife, water quality, timber production, recreation, aesthetics, and soil productivity. This is analogous to the meaning ascribed to forest resources by the Minnesota Forest Resources Management Act of 1982 (see section 4.1.1).

3.1.1 Historic Overview of Minnesota's Forests

History provides some perspective within which future Minnesota forest scenarios, and the assumptions underlying them, can be judged. Such perspective is important for policymakers in setting strategic direction and in trying to comprehend how current policy decisions and program directions may shape the future.

Land ownership patterns, forest types, and many other forest characteristics which exist in Minnesota today were strongly influenced by history. Prior to European settlement in the 19th century, the forests of Minnesota already had a long history of use by Native Americans. That use was as a source of food and shelter, and it also served to provide for a range of spiritual values. Additionally, fire was a common forest management tool employed by Native Americans.

In the early 19th century, Minnesota's forest acreage was extensively and largely dominated by conifers. White pine attracted the most attention and was essentially all logged between 1880 and 1910. Subsequently, attempts were made to settle these lands. The combination of heavy slash accumulations following logging and minimal fire protection resulted in catastrophic fires which destroyed property and took human lives. Soil productivity was also affected by the destruction of leaf and needle accumulations.

Following logging, speculators became interested in these low productivity, partially cleared areas and began selling them as agricultural lands to Easterners and immigrants looking to settle further West. Large transfers of public domain lands into private hands occurred in the late 1800s and in the early 1900s. However, this trend of transferring public forest land to private ownership began to change with the establishment of the national forests early in this century. By that time, however, vast acreages of the most productive land had passed into private ownership.

Of the federal land that remained, the majority was in what is now the BWCAW and land within the Chippewa National Forest specifically reserved by treaty. Subsequent land exchanges consolidated federal ownership of forest land, and the remaining land outside of consolidated ownerships was transferred to the fledgling state agency, the Department of Conservation, via various land grants. Since the late 1920s, the USDA Forest Service has continued to purchase land, primarily to increase national forest acreage within established forest boundaries, but not for the sole purpose of growing timber.

In the 1930s and 1940s, large-scale tax forfeiture occurred and the state Department of Conservation acquired privately owned lands that had been unable to support viable agriculture. The fact that these lands had been considered viable agricultural lands at one time distinguishes them (from a productivity standpoint) from the federal lands, as the majority of the latter never supported agriculture. Again, the private owners generally retained the most productive agricultural land (and timberland), which is concentrated in south, central, and northwestern Minnesota.

At the time when large-scale transfers of tax forfeited lands back to public ownership was occurring, the recipient state and county agencies did not have the personnel, money, or expertise at the time to actively manage these lands. Consequently, many of these acres gradually began to convert back to forest naturally. This new forest was largely hardwood with a large component of the pioneer species aspen. This species composition might have been different if state and county agencies had been better equipped to manage these lands. Reforestation by large-scale planting of conifers was a common practice on federal lands, and would probably have been practiced more extensively by state and county agencies if funding had been available.

3.1.2 Forest Land Area

Statewide Area of Forest Land

Forest lands currently occupy about 16.7 million acres in Minnesota, or about 33 percent of the state's 50.8 million acres of land. In Minnesota, the most comprehensive information on general characteristics of forest resources is the statewide forest survey conducted by the USDA Forest Service through its FIA project, based at the agency's North Central Forest Experiment Station in St. Paul. The first survey was conducted in 1934–36, and subsequent surveys or major updates were developed in 1953, 1962, 1977, and 1990. Three major categories of forest land recognized in the surveys are:

1. *Timberland or commercial forest*.—Forest land with trees that are growing fast enough so that they are potentially available for commercial use, and on lands not legislatively designated as an area where timber harvesting and other forest management prescriptions cannot occur.

2. *Unproductive forest or woodland*.—Forest land that, even though potentially available for harvesting, is not suited for growing trees that could be used for commercial purposes. Lands with poor soil, such as rocky areas on the Canadian shield in northern Minnesota and waterlogged peatlands are examples.
3. *Reserved Forest*.—Timberland and unproductive forest land legislatively withdrawn from timber utilization. Examples of reserved forest include state parks and the BWCAW.

Table 3.1 summarizes the survey results from 1936 to 1990. The area of all forest land has declined from 19.6 million acres to the current 16.7 million acres over the 54-year period. This is approximately half the area of forest prior to European settlement. The loss of forest area has occurred as a consequence of expanding agriculture and urbanization. The area of reserved forest land has risen from 400,000 acres in 1936 to 1.1 million acres today. Most of this increase came in the 1970s, when the BWCAW and Voyageurs National Park were legislatively established. Together these two areas of reserved forest land comprise over 80 percent of Minnesota's reserved forest acreage. The increase in reserved forest and the decline in total forest land over the last 50 years has led to a decline in timberland of about 3.4 million acres, or 19 percent. Caution should be used in interpretation of changes in unproductive forest land, as the definition of unproductive forest land differed between 1936 and 1953 and 1962 and again between the 1977 and 1990 FIA surveys. Today, most of the unproductive forest land in Minnesota consists of black spruce and tamarack forests growing on peatlands. Currently, timberland, reserved land, and unproductive or other forest lands make up about 88, 7, and 5 percent, respectively, of the state's total forest land base.

The 1990 FIA forest survey also shows an additional 953,600 acres of nonforest with trees (e.g., cropland or pasture with trees, windbreaks, marshland with trees, and urban areas with trees). These areas are important as tree cover itself and because they can represent land moving in or out of a forested classification or land use.

Table 3.1. Forest land area in Minnesota by major land class for 1953–90 (thousand acres).

Year	All Forest Land	Timberland	Reserved Forest Land	Unproductive or Other
1990	16,715[a]	14,773	1,113	828
1977	16,709	13,695	1,179	1,835
1962	18,445	15,412	470	2,563
1953	19,344	18,098	428	818
1936	19,615	18,215	400	1,000

Source: Jaakko Pöyry Consulting, Inc. (1992a).
Note: Portions of this and other inventory-related tables were drawn or derived from USDA Forest Service FIA documents and/or test data.
[a] Increases in all categories from 1977 to 1990 are more the result of a survey method correction than actual gain.

Distribution of Forest Land Area Within the State

A tabulation of forest land by ecoregion (table 3.2) shows that about half of total forest land occurs in heavily forested ecoregion 4 (Central Pine-Hardwood Forests). Extreme north and northeast Minnesota (ecoregions 1, 2 and 3) are also heavily forested and contain major acreages of the state's forest land. Ecoregions 5 and 6 cover the Prairie-Forest transition zone, where the largest area of former forest land has been converted to agriculture or other uses. Although the acreage of forest land in these two ecoregions is substantial, it represents a relatively small proportion of the land area within the ecoregion. Forest land in ecoregion 7—the Prairie region—consists mainly of scattered woodlots and stands of trees along streams and rivers.

Table 3.2. Forest land area in Minnesota by major land class and ecoregion, 1990 (thousand acres).

Ecoregion	All Forest Land	Timberland	Reserved	Unproductive
1	3,372.0	2,862.4	21.1	488.5
2	2,023.7	1,049.8	941.9	32.0
3	908.0	871.7	30.6	5.7
4	8,172.9	7,813.1	84.5	275.3
5	934.7	910.3	15.4	9.0
6	637.2	619.9	14.0	3.3
7	666.3	646.2	5.6	14.5
Total	16,714.8	14,773.4	1,113.1	828.3

Source: Jaakko Pöyry Consulting, Inc. (1992a).

More than half of all timberland occurs in ecoregion 4 (Central Pine-Hardwood Forests), and 85 percent of the reserved acreage is in the ecoregion 2 (Border Lakes), mostly in the BWCAW. Most of the unproductive forest is in the Red Lake Peatlands of ecoregion 1 (Glacial Lake Plains), with a substantial area also in various peatlands in ecoregion 4.

3.1.3 Description of Minnesota's Forest Resources

Forest Types

Minnesota's forest land can be classified into 14 *forest types* (sometimes also called *covertypes*), which is what was done for the GEIS, based on the proportion of various tree species that compose a given stand (an area of forest about 1 acre in size). Each forest type bears the name of one or two tree species that form a majority or plurality of wood volume in the stand. Although the types have simple, short names, most stands have a considerable mixture of species. Many stands contain five or six species of trees. As a result, a stand may be classified as aspen, when, for example, aspen comprises only 30 percent of the wood volume, and other species like balsam fir, white pine, white spruce, and red maple each comprise 15 to 20 percent of the total volume. Aspen stands may also vary greatly in species composition from place to place. For example, in ecoregion 5, an aspen stand may include substantial amounts of red oak and sugar maple, with few conifers. In ecoregion 2, an aspen stand may include substantial amounts of spruce and fir, with no maple or oak.

The forest types and their extent in Minnesota, as estimated in 1990, are described in table 3.3. Currently, the aspen forest type occupies the largest area, about one-third of the total. However, as mentioned above, many aspen stands have considerable components of either hardwoods or conifers, and so are more diverse than the name suggests. Black spruce occupies the largest area of any conifer type, due to its ability to grow on peatland soils. Minnesota has the largest area of these soils in the lower 48 states. Other major forest types include maple-basswood, oak-hickory, and elm-ash-soft maple, each comprising 7 to 8 percent of the total forest land area.

Table 3.3. Forest type acreage for timberland, reserved, and unproductive plots, statewide (thousand acres). Based on the 1990 FIA survey.

Forest Type	Forest Land Category			
	Timberland	Reserved	Unproductive	Total
Jack pine	447.5	131.5	0	579.0
Red pine	301.6	80.4	0	382.0
White pine	63.2	3.8	1.3	68.3
Black spruce	1,322.1	126.6	533.7	1,982.4
Balsam fir	734.3	93.1	12.5	839.9
Northern white cedar	680.5	25.1	38.3	743.9
Tamarack	705.1	8.9	110.7	824.7
White spruce	93.8	39.9	0	133.7
Oak-Hickory	1,190.4	9.5	13.4	1,213.3
Elm-Ash-Soft maple	1,291.5	42.8	33.1	1,367.4
Maple-Basswood	1,396.7	17.0	0	1,413.7
Aspen	5,115.4	422.1	30.3	5,567.8
Paper birch	834.7	94.9	2.1	931.7
Balsam poplar	427.7	7.1	8.4	443.2
Other	0	10.4	1.0	0
Nonstocked	169.9	0	43.5	222.8
Total	14,773.4	1,113.1	828.3	16,714.8

Source: Jaakko Pöyry Consulting, Inc. (1992a).

Forest Stand-size and Age Class

Foresters categorize stand-size class by the diameter at breast height (dbh) of the dominant trees. Sapling-seedling stands are dominated by trees less than 5 inches dbh, poletimber stands by trees 5 to 9 inches dbh (11 inches for hardwoods), and sawtimber stands by trees 9 inches or more in dbh (11 inches for hardwoods). The stands composing Minnesota's timberland are aging and more of the acreage is stocked with trees than in the past. These trends are reflected in comparisons of stand size class data over time. The data in table 3.4 show a shift of acres from the seedling and sapling category to poletimber and sawtimber classes. Sawtimber as a class rose from 12.2 percent of timberland in 1953 to 33.1 percent in 1990.

There is a simple explanation for this trend. Much of Minnesota was cutover in the late nineteenth and early twentieth centuries. Forests have become established on many formerly cutover lands and, once established, timber volume growth has exceeded removals (harvesting) and mortality. Therefore, much timberland acreage has grown into the older, larger size classes. For many covertypes the forests are much older, on average, than they were in 1953. Even though harvesting has converted older stands to young ones over that period, covertypes with little harvesting now have extensive acres of maturing stands.

Table 3.4. Timberland area in Minnesota by stand-size class, 1953–90 (thousand acres). Nonstocked indicates forest land not occupied with trees (i.e. needs planting or seeding to reforest the area).

Year	All Size Classes	Sawtimber	Poletimber	Saplings & Seedlings	Nonstocked and Other
1990	14,774	4,895	5,261	4,449	169
1977	13,695	3,135	6,956	3,435	169
1962	15,412	2,387	7,520	4,294	1,211
1953	18,098	2,017	5,281	6,317	4,483

Source: Jaakko Pöyry Consulting, Inc. (1992a).

Age class distributions are important to developing and maintaining a given forest structure and composition. When a forest has an equal number of acres in each age class, the age class distribution is considered *balanced*. Balanced age class distributions in turn assist in developing an even flow of timber yield and other forest values. Where age class distributions are unbalanced, management typically employs strategies that will replace existing stands upon harvest or natural mortality to achieve a more balanced age class structure. For example, a majority of the white pine forest area is 40 to 100 years old. There is relatively little area either older than 100 or younger than 40 years. This suggests the need for management to increase the acreage of young stands that will eventually replace the existing older stands.

The result of regrowth plus harvesting to date is reflected in the age class distributions for timberlands. A tabulation of such age class distributions for all covertypes is given in appendix 2. For reasons discussed in the next paragraph, only gross changes to age class distributions can be interpreted.

The stand age variable is difficult to accurately measure in the field for a variety of reasons: (1) difficulty in reading rings from increment cores for many species (particularly aspen), (2) variability in sample tree ages, (3) possible unintentional bias or error in choosing trees representative of stand age, (4) variability in years to reach Dbh (the usual point of measurement), (5) some stands may vary widely in age to the point of being uneven-aged, and (6) reserve stand ages were estimated from aerial photo interpretation. A stand may encompass trees with ages ranging over twenty years and still be considered even-aged. Figure 3.1 describes the age class distributions for two illustrative covertypes. Additional figures and commentary by covertype is given in section 2.3.3 of the Maintaining Productivity and the Forest Resource Base technical paper.

Figure 3.1. Age class distributions for FIA maple-basswood and aspen forest covertypes for timberland and reserved forest, 1990.

Maple-basswood

The maple-basswood forest type acreage on timberlands is dominated by stands from 50 to 70 years of age (see figure 3.1). This is typical of stands that developed in the early part of this century after logging and following the decline of agriculture. Like several other hardwood forest types, low demand has led to an unbalanced age class distribution with few younger stands present. The reserved forest acreage in this type is small and concentrated in the middle to older age classes in the central and southern portions of the state. The species comprising the covertype are generally shallow rooted, long-lived and respond to release or disturbance to advanced ages. Two site quality situations are recognized: (1) stands largely composed of sugar maple on well-drained sites, and (2) less well-drained or excessively drained sites with significant amounts of red maple and other hardwood species. Stands in the first category have the potential to grow sawtimber. Stands in the second category are typical of sites where tree form is poor and sawtimber quality is low. With time these stands can become uneven-aged. This covertype has a rich overall tree species composition compared to most pioneer covertypes.

Aspen

Aspen is a fast growing but short-lived tree species that typically reaches maximum timber volume production in the 25- to 50-year age range. Beyond that, growth diminishes and mortality and decay losses can reduce stand yields. However, in the northern part of the state, stands are capable of growing to more than 100 years of age. Individual trees may far exceed that. Like other types, most of the present stands originated in the first half of this century. Some observers have referred to this as a *wall of wood* moving to older age classes. However, harvesting over the last 20 years has led to a more balanced distribution of acres by age class, i.e., harvesting of older stands followed by prolific natural regeneration by suckering has led to development of substantial acreage of younger or replacement stand acreage. As shown by figure 3.1, there is a shortage of acreage in 25- and 35-year-old age classes, raising concerns about the adequacy of aspen timber supply in the period 2010–20. In managed stands, rotation ages are typically shorter than 50 or 60 years. The acreage of older stands suggests that these stands have not been utilized for one or more of the following reasons: lack of demand; inaccessibility or unavailability due to insufficient stumpage prices or constraints placed by owners. Silviculturally, this is also a concern because older stands on many sites do not sprout and regenerate well. Thus how these stands are managed and harvested over the next several decades will have a large impact on the continuity of timber supplies for major industries. The age class distribution of aspen is also considered important for wildlife, particularly game species that are favored by early successional stages of vegetation. The current large acreage of this type insures that it will be a major factor in both timber and nontimber management efforts for many decades.

Stand age is also important as a major factor in determining tree size, quality, and value. For some species, e.g., red oak, age may be deceptive as demand has been high for some time and the remaining quantity of high quality timber is a concern. Locally, quality is problematic and depends heavily on the grazing and other history of stands.

Growing Stock Dynamics

With or without harvesting, Minnesota's forests will change considerably in the coming decades. Such change will follow from aging, stand dynamics, or succession to different species, and natural forces such as fire, drought, windstorms, insect outbreaks, and disease. Harvesting can accelerate or slow such changes depending on the type and extent of the harvesting.

The stand aging and dynamics associated with the increase in acreage in the larger tree size classes in table 3.4 have also led to a dramatic accumulation of growing stock as shown in table 3.5. From 1936 to 1990 the net growth on Minnesota's forest land has exceeded the removals from harvesting to the extent that growing stock has more than doubled. Growing stock volume considers only those trees that satisfy typical size and quality standards for merchantability and then only the utilizable portion of those trees. The volume of dynamics (rate of resource change) is also informative. The rate of resource change has three components: *net growth*, *mortality*, and *removals*. Net annual growth of growing stock is defined as the annual change in volume of sound wood in live sawtimber and poletimber trees and the volume of trees entering these classes as ingrowth, less volume losses resulting from natural causes. Table 3.6 describes the trends in the rate of resource change since 1936.

Table 3.5. Growing stock volume and sawtimber volume on timberlands in Minnesota by softwoods and hardwoods (million cubic feet).

	Growing stock (million cubic feet)			Sawtimber (million board feet)		
Year	All Species	Hardwood	Softwood	All Species	Hardwood	Softwood
1990	15,091	10,460	4,631	34,657	22,489	12,168
1977	11,455	7,978	3,477	24,608	16,077	8,531
1962	9,444	6,060	3,384	14,875	8,742	6,133
1953	7,235	4,406	2,829	12,538	7,499	5,039
1936	6,903	3,652	3,251	12,455	5,867	6,588

Source: Jaakko Pöyry Consulting, Inc. (1992a).

Table 3.6. Comparison of average net annual volume growth, mortality and removals from 1936, 1953, 1962, 1977 and 1990 from original survey reports (million cubic feet) for growing stock.[a]

	Year	All		Hardwoods		Softwoods	
			Percent[b]		Percent		Percent
Net growth	1990	367.1	2.4	254.9	2.4	112.2	2.4
	1977	348.9	3.0	229.1	2.9	119.8	3.4
	1962	364.2	3.7	257.4	4.2	106.8	3.0
	1953	384.6	5.3	267.0	6.1	117.6	4.2
	1936	373.1	5.4	229.1	6.3	144.0	4.4
Mortality	1990	219.6	1.4	153.1	1.5	66.5	1.5
	1977	141.5	1.2	107.8	1.4	33.7	1.0
	1962	111.0	1.1	55.6	0.9	56.4	1.6
	1953	173.0	2.4	105.0	2.4	68.0	2.4
	1936	95.4	1.4	57.2	1.6	38.2	1.2
Removals	1990	207.6	1.4	154.2	1.5	53.4	1.2
	1977	193.6	1.7	124.8	1.6	68.8	2.0
	1962	125.6	1.3	63.1	1.0	62.5	1.7
	1953	154.2	2.1	76.2	1.7	78.0	2.8
	1936	161.3	2.3	82.9	2.3	78.4	2.4

Source: Jaakko Pöyry Consulting, Inc. (1992a).
[a] Estimates vary by procedure and assumptions for each survey area thus these values are only approximately comparable.
[b] Percent of survey report growing stocking volume.

3.1.4 Nontimber Resource Contributions of Forests

Minnesota's forest resources provide a variety of nontimber values important to addressing environmental, economic, and amenity interests and objectives. Key among these are the following:

Outdoor Recreation

Hiking, fishing, hunting, and camping are just a few of the outdoor recreation activities that take place in a forested setting. With over 12,000 lakes, 90,000 miles of streams and rivers, and 16.7 million acres of forest land, together with the fish and animals that these water and forest resources support, Minnesota is endowed with abundance of recreational opportunities.

Minnesotans actively engage in many outdoor recreation activities, with an average participation of 225 hours per year. A survey conducted in 1985 indicated that the most popular activities, in terms of hours spent annually per capita, were walking/hiking (18 percent of the hours), fishing (12 percent), biking (12 percent), and driving (8 percent) (figure 3.2). Together they accounted for 50 percent of reported outdoor recreation hours. Next in importance were swimming (6 percent), boating (5 percent), hunting (4 percent), and nature observing (4 percent), which together accounted for another 19 percent of reported outdoor recreation hours. Sightseeing, camping, and golfing accounted for an additional 9 percent.

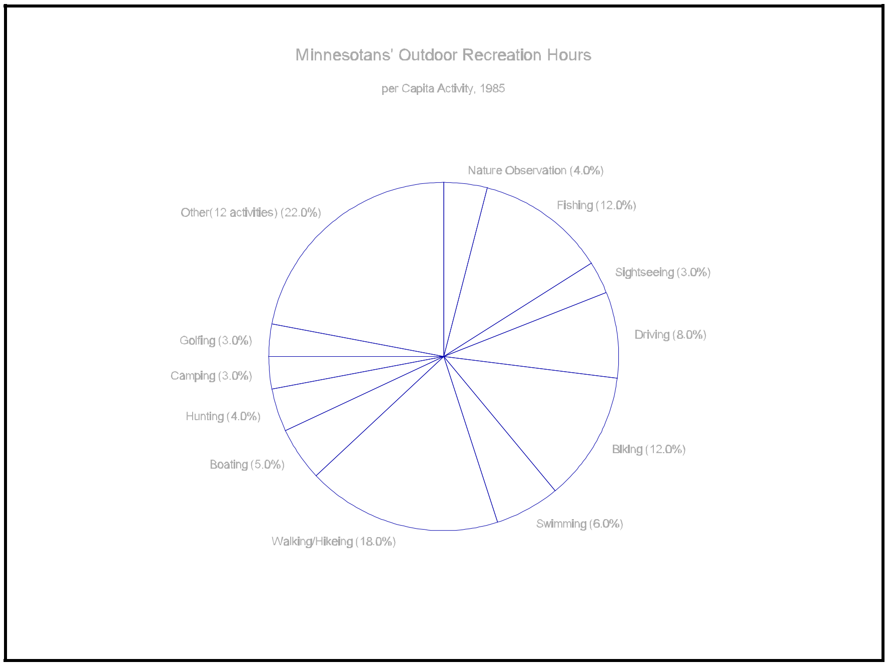

Figure 3.2. Hours spent annually in outdoor recreation by Minnesotans, 1985. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

Eighty percent of all outdoor recreation activities occur in northeastern Minnesota, in ecoregions 2, 3, and 4. The Central Pine-Hardwood Forest (ecoregion 4) accounts for at least half of all outdoor activities, except for canoeing, 40 percent of which occurs in the Border Lakes (ecoregion 2) and 19 percent in the Superior Highlands (ecoregion 3).

Economic Importance of Outdoor Recreation

The MNDNR conducted a 1985–86 outdoor recreation and expenditure survey of residents, and a 1978 summer outdoor recreation and expenditure survey of visitors to Minnesota. These surveys were used to develop estimates of statewide outdoor recreation travel-related and equipment expenditures in 1985 dollars. Annual travel-related expenditures in the state for outdoor recreation amounted to $1.2 billion in 1985 dollars. Of this, Minnesota residents accounted for $854 million (69 percent) and nonresidents $386 million (31 percent). Transportation, groceries, restaurants, and lodging accounted for 77 percent of the expenditures for outdoor recreation travel (figure 3.3). Expenditures for travel-related equipment amounted to an additional 8 percent of the total.

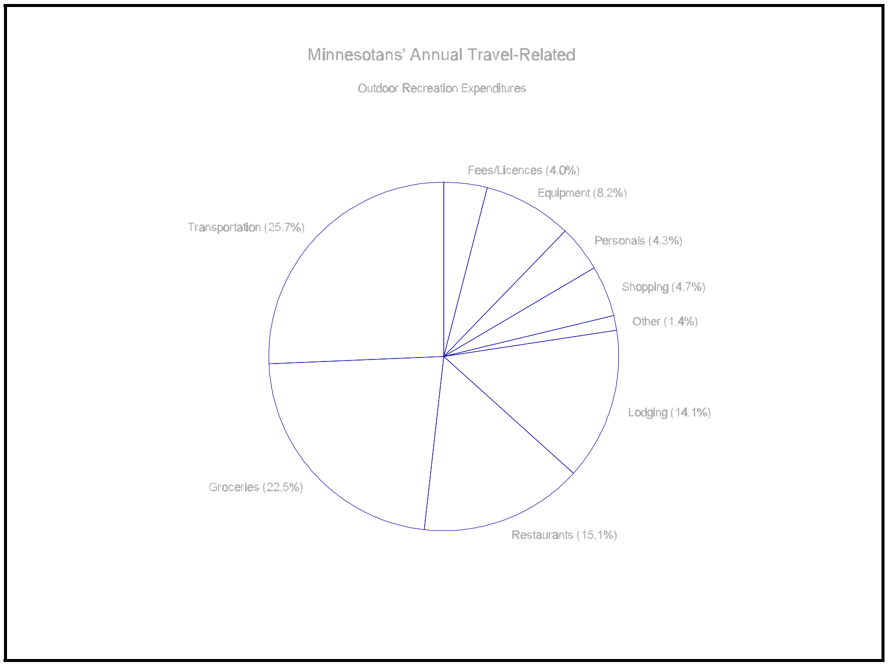

Figure 3.3. Annual travel-related expenditures for outdoor recreation by Minnesotans, 1985. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

Equipment purchases by Minnesotans were dominated by boats (including motors and accessories), which accounted for 41 percent of the total (figure 3.4). Large recreational vehicles (RVs) accounted for an additional 10 percent of equipment expenditures. Bikes, hunting (equipment and clothes), clothing and footwear (except for fishing and hunting), and sports (equipment not listed elsewhere) each accounted for approximately 8 percent of equipment expenditures. Recreational transportation (snowmobiles, 3-wheelers, and 4x4 trucks), fishing (equipment and clothing exclusively for fishing), and other (camping and nonconsumptive use equipment) accounted for the remaining 18 percent.

The direct and indirect impacts of outdoor recreation expenditures in Minnesota generated 58,000 jobs, primarily in the wholesale/retail sector and the services sector. These jobs amounted to 3.3 percent of the total number of jobs in the state. Outdoor recreation and tourism was most important to the regional economy of the northeast, accounting for over 10 percent of total economic output in that region.

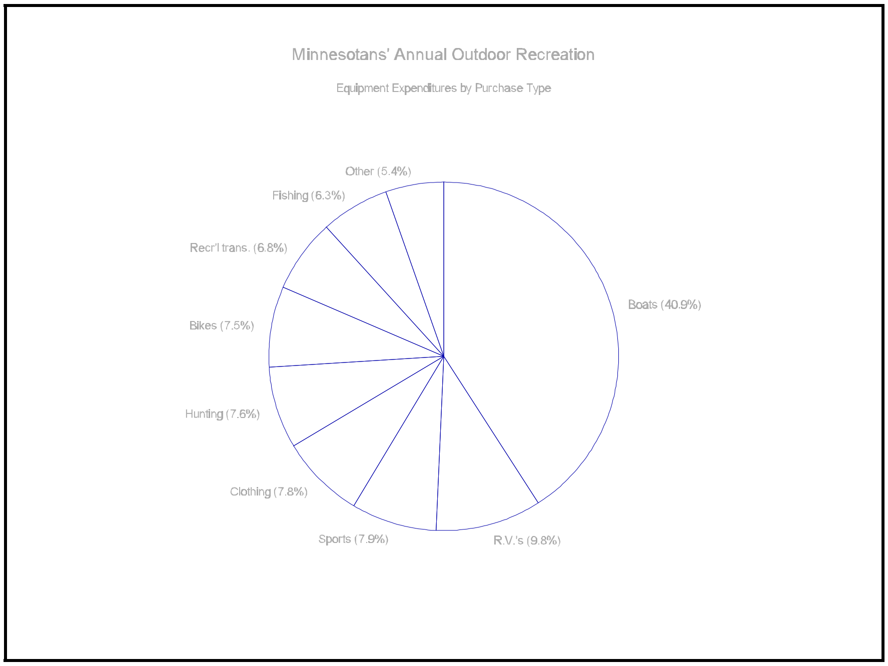

Figure 3.4. Annual expenditures on equipment purchased for outdoor recreation, by type of purchase, by Minnesotans, 1985. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

Aesthetic Values-Attractiveness of the Forest

Several factors related to landform and landcover contribute to the attractiveness of a forested landscape to outdoor recreationists and tourists. Landform dimensions generally considered attractive include steep slopes, diversity of slope steepness, ability to see water, and diversity of water features such as lakes and streams of different sizes in one landscape. People also seem to derive aesthetic enjoyment from "outdoor rooms," which provide visually bounded spaces, such as a small lake surrounded by tall trees, or a sense of canopied space within a forest with vertical walls and ceiling provided by trees. Landcover dimensions associated with high aesthetic value include species diversity within stands; diversity of vegetation types on the landscape; presence of large old trees; vegetative distinctiveness, such as fall color of maple trees or the white bark of paper birch; the condition of the forest floor with respect to amount of dead wood; and the extent of ground-cover vegetation.

Cultural and Historical Values of the Forest

Forests are often the setting for important cultural and historic resources. Minnesota's heritage resources represent values that are important to Minnesotans. Heritage resources reflect the history, contributions, and ongoing cultures of the ethnic groups that created this state. The following types of heritage sites are recognized in Minnesota:

Cultural Landscapes are a collection of features which represent interaction between humans and the environment. People may assign cultural meaning to natural features or features which have been made or modified by humans.

Standing Structures include buildings and structures made and used by people, generally in the recent past. Standing structures are rare within the timberlands.

Archaeological Sites are located on or below the surface of the ground or under water. They include two major categories: Native American sites such as the remains of large and small villages, camps, and processing sites; and Euro-American sites such as fur trade posts, homesteads, and logging camps. Most of these sites are not visible at the ground surface and require special techniques to locate.

Cemeteries may contain the remains of one or more human beings and are common on forested lands in Minnesota. These include Native American and Euro-American cemeteries.

Traditional Use Sites are locations which have been historically used by one or more groups of people for some type of activity. They may lack the physical evidence of artifacts or structures, and are often characterized by plants, animals, and/or topography which are of cultural and religious significance to Native Americans.

Biological Values of the Forest

The biological diversity of forests is of immense ecological, social, and economic importance to the world. Ultimately, the sustainability of forest resources, both economically and ecologically, depends on the maintenance of biodiversity, for the following reasons:

Forests contain genetic strains of forest trees and other plants which are adapted to local climate and site conditions. Minnesota has many species which reach either the northern or southwestern edge of their geographic range in the state. Currently, these species may be rare at the edge of their range, but they may become dominant in the future. If global warming occurs, local genetic races of trees from near the edge of the species range that are adapted to climatic extremes may help maintain forest productivity. For example, sugar maple has several isolated populations beyond the northern edge of the contiguous range of the species along the North Shore of Lake Superior (ecoregion 3). If the climate of northeastern Minnesota becomes warmer, these isolated sugar maple stands would serve as nuclei for new northern hardwood forests that would be more productive than the current birch-spruce-fir forests, which would be under heat and drought stress.

Forests often contain local populations with natural resistance to disease. Scientists who develop disease resistant varieties of crops and forest trees often search wild populations for individuals which appear to have genetically conferred disease resistance. The disease resistance can often be transferred through breeding to other populations which may have superior growth rates or form. Using this technique, varieties of white pine resistant to blister rust and varieties of American elm resistant to dutch elm disease have been developed.

Forests often contain species which may produce new economically valuable products. It is impossible to predict when an apparently unusable plant may, at some future date, produce a necessary product or allow a new local industry to develop. An example of an unexpected product is ginseng (*Panax quinqefolium*), a small herb of old growth sugar maple forests, that is now listed as of special concern in Minnesota. Ginseng is in demand for medicinal use in oriental countries. Farmers in north central Wisconsin, a region where ginseng was once abundant in the wild, used local wild stocks to start up ginseng farms, and these expanded rapidly in the 1970s and 1980s. Today, ginseng farming is a significant portion of the agricultural economy of north central Wisconsin.

Biological diversity of forests is essential for aesthetic and recreational values in Minnesota. Landscapes managed to enhance biodiversity include a large variety of forest types which have important implications for tourism, a major industry in Minnesota. Many people visit Minnesota to see forest wildlife such as Bald Eagles, owls, hawks, gray wolf, white-tailed deer, and black bear. These species range widely and use a variety of special habitats, such as isolated stands of oaks or large pines. Many songbirds and wildflowers occur mainly in mature or old growth forests. Patches of oaks and maples provide fall colors. Management of Minnesota's forest landscape to enhance biodiversity will maintain all of these recreational resources into the future.

An important aspect of Minnesota's 19th century history was the cutting of the great forests of white and red pine. Ensuring that stands of these species are able to reestablish in representative sites throughout their original ranges is as much a cultural responsibility as it is an environmental one.

Forests exhibit ecological processes useful for management and educational purposes. Many original vegetation types were maintained in a sustainable, productive state on the landscape by natural disturbances, and forest soils developed slowly over thousands of years. The sustainability of current forest management practices can be assessed by comparing the natural rate of nutrient addition and removal from the soil by disturbances and successional processes with similar rates for managed forests. Natural disturbances of various types can hold forests at one successional stage or speed the development of a desired late successional stage. However, disturbance must be studied in its natural context before it can be applied to forest management. Ultimately, forest management will be sustainable if natural processes are used as guidelines.

Forests sequester large amounts of carbon. Trees use carbon dioxide as a major building block to make cellulose, which is incorporated into wood. An acre of red pine or oak forest on a good quality site in Minnesota can sequester 50 to 100 tons of carbon as it grows from a seedling stand to an old sawtimber stand. Since 1977 or earlier, about 2 to 4.5 million tons of carbon have been added each year to existing Minnesota forest lands (MNDNR 1991). This is because in the last several decades most Minnesota forests each year have added more wood volume than has been removed. Sequestration of carbon by forests is important because it can help counterbalance the addition of carbon dioxide to the atmosphere that is now occurring due to burning of fossil fuels.

Forests provide water resource protection. Forest resources provide important cover and mechanisms to maintain and protect water resources. As continuous vegetative cover, forests can affect the amount, timing, and quality of water yield. Forest stand density, for example, can influence the timing of runoff peak discharges, thereby lessening the impact on stormflow and flooding. Even though much of Minnesota's topography is fairly flat, forests also serve as stabilizing forces to protect against soil erosion and sedimentation problems in waterbodies. The forest floor and soils are also important in filtering and modifying chemical inputs from nearby agricultural or developed areas. Forest canopies in riparian areas also reduce the input of organic matter in adjacent waterbodies and the amount of light reaching the water surface, factors which affect species composition, growth, and production of the animals that inhabit the water resource.

3.2 Forest Ownership and Management

3.2.1 Forest Ownership

Private individuals and corporations, other than the forest industry, own the largest area of Minnesota timberland—about 6.4 million acres or 43 percent of all timberland (table 3.7). The state is the largest public landowner with over 3 million acres of timberland, followed by counties and the national forests. The forest industry owns about 5 percent of all timberland in the state.

The ownership pattern of timberland in Minnesota has changed only slightly since 1953 (table 3.7). Much of the change is the result of decreases in the amount of timberland due to reservation (BWCAW and Voyageurs National Park) and reclassification of land from timberland to unproductive and then back to timberland status.

Table 3.7. Timberland area in Minnesota by ownership class 1953–90 (thousand acres).

Year	All Classes	National Forest	State	County	Other Public	Forest Industry	Other Private
1990	14,774	1,821	3,078	2,506	198	751	6,420
1977	13,695	1,715	2,651	2,342	155	772	6,060
1962	15,412	2,142	2,639	2,732	126	716	7,057
1953	18,098	2,195	3,484	3,619	143	509	8,148

Source: Jaakko Pöyry Consulting, Inc. (1992a).

Reclassification of timberland into the reserved land use category accounts for most of the reduction in timberland for federal ownership. The decrease on other lands is more difficult to explain. Past large-scale shifts in timberland acreage have been closely linked to demand for agricultural land. During periods of higher commodity prices for agricultural goods, timberlands have been cleared and used for cropland. Also, other private includes Native American lands. Because these lands contain a substantial portion of unproductive forests, shifts in the amount of timberland may be the result of changes in definitions shifting forest land between unproductive and timberland categories. Also, the other private class in some areas is being increasingly fragmented as it is being handed down to estate heirs over time.

Use of marginal agriculture lands for cropping has long been a concern among federal and state governments. In response, new federal and state programs have been developed in the past decade to convert these acreages back to tree or shrub cover, much of which would eventually result in its reclassification to timberland. However, these are new programs while the conversion of woodlots to cropland has been consistent for many years. Note that the state has a long history of programs to reclaim marginal farmland, dating back to the soil bank conservation programs of the 1930s.

Urban expansion is also a significant factor in timberland loss on private ownerships, at least around major metropolitan centers such as the Twin Cities, and in the St. Cloud/Rochester corridor—areas where a high percentage (higher than the state average) of forest land is likely to be classified as timberland due to the generally more productive soils.

Studies to determine the cause of timberland area change suggest the cases vary in a complex manner over time and by region of the state. Table 3.8 indicates the ownership of Minnesota timberlands by ecoregion. National forest timberlands are the most concentrated, with 45 percent of all USDA Forest Service lands occurring in ecoregion 4 and the remainder in ecoregions 1 through 3. Industry lands are only slightly less concentrated— 49 percent occur in ecoregion 4 and 36 percent in ecoregion 1.

Approximately 73 percent of county timberland is in ecoregion 4 and 14 percent in ecoregion 1. Approximately 46 percent of state lands are in ecoregion 1 and 36 percent in ecoregion 4.

Table 3.8. Timberland by ownership class and ecoregion 1990 (thousand acres).

Ecoregion	Total	National Forest	State	County	Other Public	Industry	Other Private
1	2,862	125	1,414	347	63	273	640
2	1,050	590	151	119	4	49	137
3	872	289	114	182	2	61	224
4	7,813	817	1,204	1,819	63	367	3,543
5	910	0	51	22	32	0	805
6	620	0	67	6	20	1	526
7	647	0	77	11	14	0	545

Total	14,774	1,821	3,078	2,506	198	751	6,420

Source: Jaakko Pöyry Consulting, Inc. (1992a).

3.2.2 Management Structure

National Forests

The USDA Forest Service is the largest agency of the U.S. Department of Agriculture. It administers two national forests in Minnesota, the Superior National Forest (located in ecoregions 2, 3, and northeastern part of 4) and the Chippewa National Forest (located in the northwestern part of ecoregion 4). Each national forest has a forest supervisor who oversees forest staff, helps formulate regional and forest-level policies, and helps disseminate research information. The forest supervisor also works to accomplish state and private forestry program objectives, and meets regionally allocated production targets for goods and services on the forest.

Each of Minnesota's two national forests is divided into five districts. Each district is headed by a district ranger whose primary responsibility is on-the-ground management of national forest programs, which is carried out by field personnel. This level of the national forest system generally has the most direct contact with local government officials, forest users, and other segments of the public.

The grouping of Minnesota's national forest lands into two large blocks allows management for multiple use objectives that can only be achieved at the landscape-level. Diverse goals, such as maintaining large nonmotorized recreational areas with appropriate buffer zones, riparian management zones, large areas of old uneven-aged forest management, and areas of even-aged forest management, can be accomplished simultaneously on the national forests while still producing enough timber to enhance the local timber industry and practicing sustained yield forestry. Such management is more difficult to effectively practice where ownership patterns are fragmented, as is often experienced on state administered forest lands and, to a greater degree, county managed forest lands.

In terms of the degree to which large areas of contiguous forest land occurs across the landscape, national forests are the most aggregated, followed by state and then county forest land. These differences in management are also reflected in availability of timberland for harvest. Availability is estimated at 87 and 53 percent on the Chippewa and Superior national forests, respectively, but 95 percent on state and county forest lands.

MNDNR Division of Forestry

The Division of Forestry is headed by a director located in St. Paul, with field offices organized into five regions: Bemidji, Grand Rapids, Brainerd, Rochester, and Metro. The regions are in turn divided into areas (16 total) and field stations (69 total). The division follows a multiple use management plan with responsibility for timber production, enhancement of outdoor recreation, biodiversity, and other uses of state forest lands.

The regional administrative level provides centralized services, specialist services, policy implementation, and supervision for the areas within the region. The area administrative level has similar duties for the field stations within the area. The field station administrative level carries out the on-the-ground management activities of the Division of Forestry.

In contrast to the USDA Forest Service whose entire ownership is essentially contiguous, the MNDNR Division of Forestry is less able to carry out the landscape-scale multiple use objectives—such as simultaneous primitive areas and timber production on the same forest. This is due to the smaller size of individual state forest holdings. For example, MNDNR has an old growth program whereby *old growth stands* of 20 to several hundred acres in size are reserved from harvest. This is in contrast to the national forests, which are capable of creating an *old growth landscape*, such as the BWCAW in Superior National Forest. The state forests have emphasized timber production more than the national forests, but less than the county forests, as described below.

County Management System

Minnesota is one of only two states in the U.S. with an extensive county managed land base. Counties manage 2.5 million acres of forest land. St. Louis County has the largest county land system at 744,800 acres, followed by Koochiching (278,000 acres), Itasca (255,700), and Cass (232,900). Four additional counties manage at least 100,000 acres, and four more manage 50,000 to 100,000 acres. Technically, these lands are owned by the state, but there is a statutory trust in each county where such lands exist. All lands that now compose the county land base became county land through tax forfeiture. The state makes annual payments to counties in lieu of taxes that would otherwise be generated by these lands.

Each county's land base is managed by a land commissioner, county auditor, or, for counties with small amounts of forest land, the MNDNR. The vast majority of county forest land is concentrated in a few counties with land commissioners and a county land department. Land commissioners are appointed by county boards and function as the administrators of the county land system. In counties with large land areas, lands are often divided into districts or areas, with management of each area under a resources manager.

The primary focus of management on county forest lands in Minnesota has been generation of revenue from timber sales, which in turn also helps support the local forest industry job base. Although the county lands technically belong to the state, their management was specifically excluded from the Forest Management Act of 1982, which provides for multiple use management of all state owned forest resources. For counties with significant forest land, the tracts are generally large and contiguous, second only to the national forests. Where counties have smaller holdings, they are mostly in small, scattered parcels, so that management for fish and wildlife and recreation and aesthetics, which often require large contiguous areas of forest, have been difficult, and consequently of secondary importance in county forests. Also important, the primary reason some counties do not manage for resources other than timber is because they have no legal mandate to do so.

However, to a certain degree, county managers cooperate with state and national forest wildlife and recreation management programs, as these lands often surround county forest lands. Where practiced, this cooperation also allows counties to take advantage of state and national forest expertise and personnel, which the counties could not afford on their own. One difficulty in fully assessing this aspect is the lack of specific data regarding actual cooperative management acres by county and by resource use.

3.3 Minnesota's Primary Forest Products Industries

Primary forest products industries utilize roundwood (logs or other round sections cut from trees for industrial or consumer use) to produce output, much of which is used as a raw material by other economic sectors. Industries that utilize wood-based products, but not roundwood, are referred to as secondary forest product industries. The major forest products industries in Minnesota include: (1) pulp and paper, (2) hardboard, (3) waferboard (also known as flakeboard) and oriented strand board (OSB), (4) lumber, (5) veneer, and (6) treated wood. The following section discusses the facilities, type of product, and employment generated for these major categories in Minnesota.

3.3.1 Pulp, Paper, and Hardboard

Minnesota has 13 mills that produce pulp, paper, and/or hardboard (table 3.9). Of these, ten produce pulp and purchase roundwood on the open market. There are seven pulp and paper mills in Minnesota. Six of these mills purchase roundwood; the Potlatch paper mill in Brainerd obtains the processed pulp it uses from the Cloquet mill and on the open market. In total, the six pulp and paper mills, other than Potlatch-Brainerd, purchase about 1.4 million cords of roundwood each year.[1] From this, they produce about a million tons of pulp each year. They also purchase about 425,000 tons of pulp each year from outside the state. Most of the purchased pulp is softwood kraft pulp obtained from Canada. These seven mills produce about 1.9 million tons of paper each year.

Many products other than paper are produced with wood pulp. In Minnesota, these include hardboard, boxboard, roofing felt, sheathing, ceiling panels, and decorative tiles (table 3.9). Superwood Corporation operates two hardboard plants in Minnesota that use about 150,000 cords of roundwood each year to produce 60,000 million square feet (3/8 in. basis) of hardboard annually. Two other companies, International Biltrite Inc. and CertainTeed Corporation, also purchase roundwood. Together, they use about 45,000 cords per year to produce sheathing and roofing dry felt. The Waldorf Corporation in St. Paul makes cardboard and corrugated boxes using primarily recycled paper.

In 1985, about 4,962 people were employed in the pulp and paper industries of Minnesota.

[1] The numbers in table 3.7 are cords per day. To obtain cords per year, multiply by 365 days per year.

Table 3.9. The pulp and paper and hardboard industries in Minnesota, 1990.

Company	Location	Hardwood Roundwood Purchases (CPD)[a]	Softwood Roundwood Purchases (CPD)[a]	Pulp Produced (TPD)[b]	Type of Pulp	Final Product	Quantity	Units (per day)
Superwood Corp.	Bemidji	82	27	100	GW[c]	hardboard	37	mmsf[d](3/8)
Potlatch Corp.	Brainerd	0	0	0	--	coated offset text and cover	329	tons
Potlatch Corp.	Cloquet	699	164	534	Kraft	coated offset text and cover	504	tons
USG Interiors Inc. Co.	Cloquet	0	0	0	--	misc.: ceiling panels, decor. tiles	--	--
Lake Superior Paper Ind.	Duluth	0	438	438	GW	SC[e] groundwood printing papers	685	tons
Superwood Corp.	Duluth	274	27	350	GW	hardboard	128	mmsf (3/8)
Blandin Paper Co.	Grand Rapids	329	315	521	GW/TM[f]	coated and uncoated printing	1,370	tons
Boise Cascade Corp.	Intn'l Falls	1,260	247	890	Kraft	business papers	1,397	tons
International Biltrite Inc.	Intn'l Falls	68	0	110	GW	sheathing	--	--
Hennepin Paper Co.	Little Falls	14	41	68	GW	bleached & unbleached printing	82	tons
Champion International	Sartell	178	164	493	GW	SC groundwood printing papers	233	tons
Champion (Cont')						lightweight coated pub. papers	548	tons
CertainTeed Corp.	Shakopee	60	0	80	GW	roofing dry felt	185	tons
Waldorf Corp.	St. Paul	0	0	0	--	clay coated boxboard	850	mmsf
Totals		2,964	1,425	3,585				

Source: Jaakko Pöyry Consulting, Inc. (1992h).

[a] CPD - cords per day.
[b] TPD - tons per day.
[c] GW - groundwood pulp.
[d] mmsf - million square feet (3/8 indicates 3/8 inch basis).
[e] SC - supercalendared paper.
[f] TM - thermomechanical pulp.

3.3.2 Oriented Strand Board (OSB) and Flakeboard

The waferboard, flakeboard, and OSB industry is relatively new. Minnesota has been at the forefront of this rapidly expanding industry. The first commercial waferboard mill in the United States was built in Grand Rapids, Minnesota, in 1974. That mill is now owned and operated by the Potlatch Corporation and produces OSB. The first commercial OSB mill in the United States is also located in Minnesota. It was built by Potlatch in Bemidji in 1981. Between 1981 and 1985, four new mills began operations in Minnesota. Two of these were waferboard mills and two were OSB mills. Recently, Trus Joist MacMillan began operating a new mill in Crosby, Minnesota, which makes parallel strand lumber, a new variant of the oriented strand technology. In total, these mills require 1.06 million cords of roundwood per year and produce 1,315 million square feet of board (3/8 in. basis) per year (table 3.10). In 1985, about 1,000 people were employed in the waferboard and OSB industries of Minnesota.

Table 3.10. The OSB and flakeboard mills of Minnesota, 1991.

Company	Location	Est. Date	Type of Board	Wood Use (K Cd/yr)[a]	Output (mmsf[b]/yr)
Potlatch Corp.	Grand Rapids	1974	OSB	265	275
Potlatch Corp.	Bemidji	1981	OSB	175[c]	220[c]
Northwood	Solway	1981	Wafer	210	300
Potlatch Corp.	Cook	1982	OSB	175	210
Louisiana Pacific	Two Harbors	1985	Wafer	100	130
MacMillan	Crosby	1991	PSL[d]	135	180
Totals				1060	1315

Source: Jaakko Pöyry Consulting, Inc. (1992h)

[a] K cd/yr - 1000 cords per year.
[b] mmsf - million square feet, 3/8 in. basis.
[c] This mill is in the midst of an expansion. Consumption is expected to increase in 1992 to as much as 315,000 cords of roundwood per year. Production will increase accordingly.
[d] PSL - parallel strand lumber.

3.3.3 Sawmills

There are an estimated 892 sawmills in Minnesota, scattered throughout the state. All of these are small by national standards. They vary in size from 1 to 100 employees. Aspen is the primary species used for sawlogs, with 82 million board feet cut and delivered in 1988. Red oak (47 million board feet cut in 1988), red pine (43 million board feet), jack pine (35 million board feet), and white pine (20 million board feet) are the next most important sawlog species. Altogether, 307 million board feet, or about 615,000 cords, of sawlogs were cut in Minnesota in 1988. Although sawlog volumes are small, sawlog values are relatively high. Thus, in value terms, the roundwood purchased by sawmills is as least as important as the roundwood purchased by either the pulp and paper industry or the waferboard and OSB industries. In 1985, about 1,495 people were employed in sawmills in Minnesota.

3.3.4 Other Primary Forest Products Industries

Other primary forest products industries include logging, veneer production, and treated wood products. The logging industry plays a unique role among primary forest products industries, serving as the supplier of roundwood to all other primary forest products industries. Thus, the logging industry could be viewed as a *preprimary* forest products industry. Data compiled by Minnesota Forest Industries indicates that there were 4,390 full- and part-time loggers in the state as of 1992. Relatively little of the roundwood produced in Minnesota is used for veneer production. However, due to the high value of veneer quality roundwood, this cannot be viewed as an insignificant industry. Veneer is more commonly produced in southern Minnesota than in northern Minnesota. Similarly, wood preservation is a small, but significant, primary wood products industry in Minnesota. Wood treatment may be classified as a secondary industry, depending on the degree of integration of the wood treatment facility. That is, if a treatment facility purchases only lumber for treatment, it would be considered a secondary wood processor. Facilities that purchase roundwood are considered primary producers.

Fuelwood may be considered another industry, but much of it is dispersed or local usage, and activity and employment is difficult to track in total. However, fuelwood consumption has recently been estimated by the MNDNR at 530,000 cords per year. Table 3.11 describes recent wood consumption in Minnesota, which with fuelwood removals totals nearly four million cords.

Table 3.11. Wood consumption from Minnesota's forests, 1991 (thousand cords).

Use	Consumption
Pulpwood, paper and paperboard	1,210
OSB and other pulpwood	1,505
Subtotal	**2,715**
Lumber	581
Fuelwood	530
Other	152
Total	**3,978**

Source: Jaakko Pöyry Consulting, Inc. (1992a).

3.4 Wood Fiber Consumption

The Minnesota forest products industry is in the midst of a significant expansion of output and wood use. Total industrial roundwood receipts increased from 91 million cubic feet in 1960 to 121 million cubic feet in 1975 and 218 million cubic feet in 1988 (table 3.12). The greatest expansion has taken place in pulpmills, where roundwood receipts almost doubled from 1975 to 1988, increasing from 84 million cubic feet in 1975 to 156 million

Table 3.12 Industrial roundwood receipts by type of mill in Minnesota, 1960, 1975, and 1988 (in million cubic feet).[a]

Kind of mill	All Species 1960	1975	1988
Pulpmills[b]	61.9	83.8	156.4
Sawmills	26.4	30.9	55.7
Other mills[c]	2.7	6.6	6.4
Total	91.0	121.3	218.5
	Softwoods		
Pulpmills[b]	29.1	28.8	33.3
Sawmills	11.5	9.7	22.4
Other mills[c]	0.1	0.3	0.9
Total	40.7	38.8	56.6
	Hardwoods		
Pulpmills[b]	32.8	55.0	123.1
Sawmills	14.9	21.2	33.3
Other mills[c]	2.6	6.3	5.5
Total	50.3	82.5	161.9

Source: Jaakko Pöyry Consulting, Inc. (1992h)
[a] Table values can be converted to cords by the approximation of 80 cubic feet per cord.
[b] Includes flakeboard plants after 1978, formerly reported in other mills category.
[c] Does not include treating plants or fuelwood receipts.

cubic feet in 1988. This data is somewhat misleading, however, as receipts at flakeboard and OSB mills were included with "other mills" for 1975 and with pulpmills in 1988. (In 1960, there were no flakeboard or OSB mills.)

Much of the increase in the reported receipts for pulpmills reflects the tremendous growth of the waferboard and OSB industries in Minnesota during the 1980s. Prior to the 1980s, receipts at these mills were not significant. Sawmill roundwood receipts also increased significantly between 1960 and 1988, rising from 31 million cubic feet to 56 million cubic feet. In percentage terms, both pulpmill (including flakeboard and OSB mill receipts) and sawmill receipts have increased by about the same proportion. Pulpmill receipts increased about 86 percent, and sawmill receipts increased 81 percent between 1975 and 1988. There was little overall change in receipts for other mills from 1975 to 1988.

A more detailed look at the expansion in pulpwood receipts (figure 3.5, table 3.13) indicates there was a slow but steady rise from 1960 to the early 1970s, followed by a decade of fairly stable receipts. Rapid growth in pulpwood receipts again occurred in the early 1980s, rising from 1.1 million cords in 1980 to 1.96 million cords in 1984. Receipts have since risen to

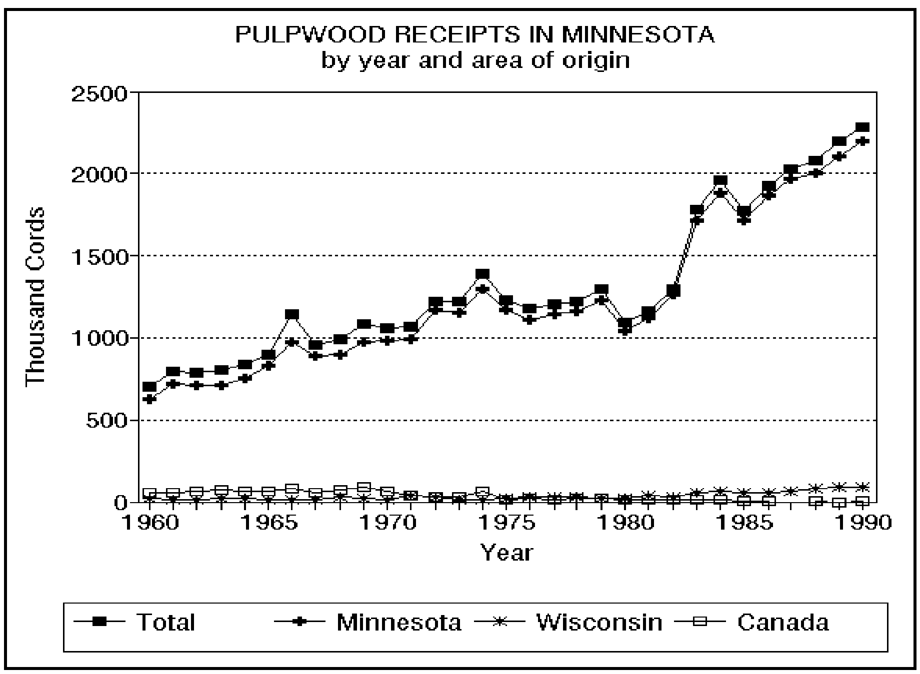

Figure 3.5. Pulpwood receipts in Minnesota, all species, by area of origin, 1960–90. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

2.29 million cords in 1990. As figure 3.5 and table 3.13 show, almost all of the pulpwood received by mills in Minnesota is produced within the state (approximately 96 percent in 1990). Only from 3 to 4 percent comes from outside the state, mostly from Wisconsin.

Table 3.13. Pulpwood receipts in Minnesota, by area of origin, 1960–90.

Year	Area of Origin				All Areas
	Minnesota	Wisconsin	Other States	Canada	
	(thousands of cords)				
1960	626	19		57	702
1961	721	14		58	793
1962	711	15		60	786
1963	712	20		73	805
1964	753	19		63	835
1965	828	8	1	61	898
1966	970	13	78	79	1,140
1967	884	15	1	58	958
1968	900	22	1	69	992
1969	977	17	2	86	1,082
1970	981	11	1	65	1,058
1971	992	35	1	36	1,064
1972	1,168	28	2	26	1,224
1973	1,152	14	29	27	1,222
1974	1,297	14	16	65	1,392
1975	1,173	20	18	15	1,226
1976	1,109	23	26	19	1,177
1977	1,149	26	19	15	1,209
1978	1,155	26	20	17	1,218
1979	1,226	21	29	19	1,295
1980	1,044	18	20	15	1,097
1981	1,119	34		11	1,164
1982	1,264	26		8	1,298
1983	1,720	53		9	1,782
1984	1,888	65		8	1,961
1985	1,714	59		2	1,775
1986	1,873	56		1	1,930
1987	1,967	62			2,029
1988	2,003	80		1	2,083
1989	2,110	89	2	0	2,201
1990	2,200	83	2	2	2,286

Source: Jaakko Pöyry Consulting, Inc. (1992h).

Figure 3.6 shows the overall trend in pulpwood receipts in Minnesota between 1979 and 1988. Clearly, there has been a steady, increasing trend. This increasing trend reflects an expansion in the number and capacity of Minnesota pulp and paper mills and waferboard and OSB mills. However, 1983 and 1984 also stand out as years when roundwood consumption was relatively high, reflecting the generally buoyant U.S. economy at that time. In addition, receipts were relatively low between 1980 and 1982, due to the recession in the early part of the decade. These numbers illustrate how receipts vary in response to current national forest products market conditions and do not reflect solely the state's industrial capacity.

Figure 3.6 also shows the breakdown of pulpwood receipts by species groups. The figure shows that the increases in pulpwood receipts are almost entirely due to increasing utilization of aspen. Figure 3.7 shows the distribution of roundwood receipts by species varied during the period from 1979 to 1988. The graph shows the trend of increasing reliance on aspen as the primary pulpwood species. However, the graph also shows that this trend appears to have been reversed, at least temporarily, beginning in 1988. The graph also shows that the proportion made up of pine receipts has been declining. Spruce and balsam fir show declining proportions between 1979 and 1987, but an increase in importance since 1988.

The expansion of the wood industry in Minnesota is likely to continue for at least the next half of a decade. Current forest industry expansion plans include $1.6 billion in investments in new plants and equipment. These new mills, if built, will consume an estimated 790,000 cords of pulpwood per year in addition to the 2,377,000 cords currently consumed.

The type of roundwood required by this growing forest products industry depends upon the manufacturing processes used, developments in the markets for their final products, and the availability of alternative raw materials. In the short run, these industries exhibit fairly specific demands for raw materials. For example, pulpmills have specific requirements regarding species mix when procuring wood. Sawmills generally require much larger diameter trees to produce dimension lumber and boards than pulpmills. Timber is not a uniform undifferentiated raw material. It varies considerably in many ways including specific gravity, pulp yield, resin content, and bark retention. Although some species may be close substitutes, others are not. Thus, the species composition and size of the available wood supply can greatly affect the amount of suitable roundwood available for any particular mill.

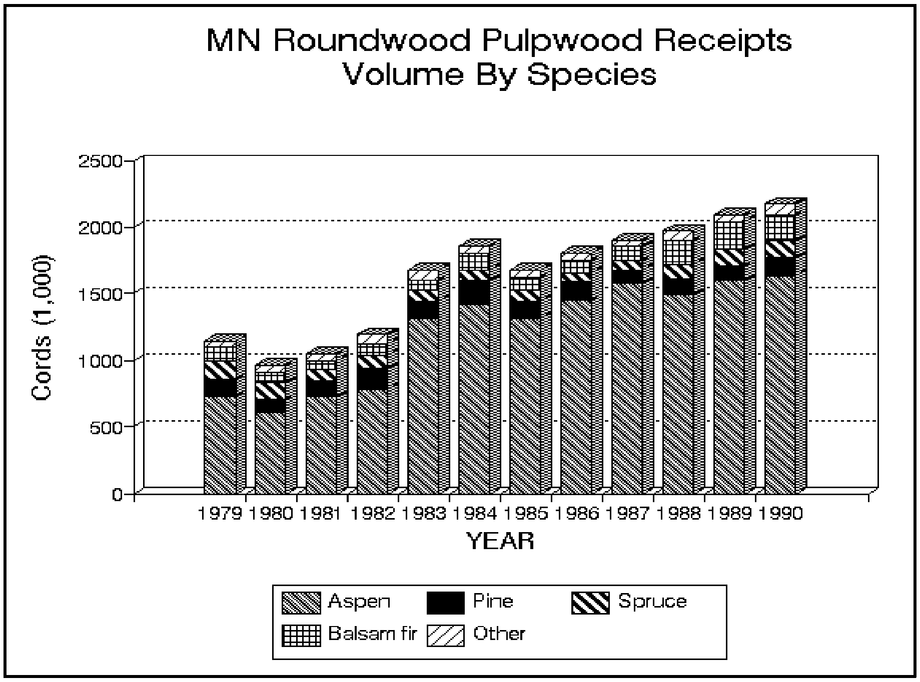

Figure 3.6. Minnesota pulpwood receipts from roundwood, volume by species, 1979–90. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

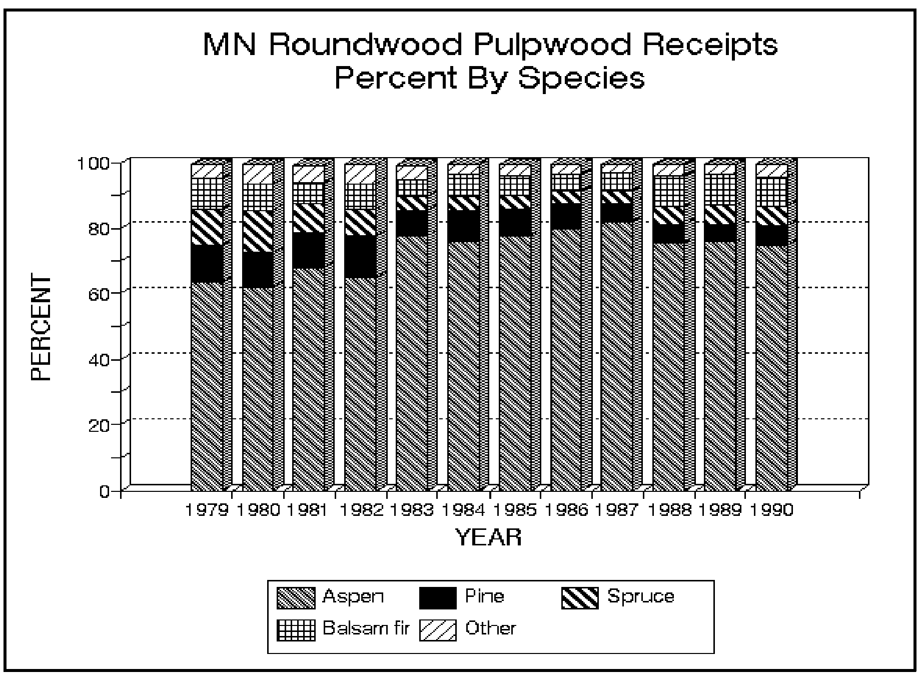

Figure 3.7. Minnesota pulpwood receipts from roundwood, percent by species, 1979–90. (Source: Jaakko Pöyry Consulting, Inc. 1992h.)

On the other hand, when increased use or declining supply of a particular type, size, and quality of wood cause the price for that raw material to go up, the incentive to find ways to use cheaper substitutes is increased. The development of the reconstituted wood panel industry—waferboard, OSB, and now parallel strand lumber (PSL)—is an example of the ability of industry to respond to changing resource availability. These industries owe their success, and possibly their existence, to the increasing scarcity of the large timber that has been traditionally used in making plywood and lumber.

3.5
Silvicultural and Harvesting Systems Used in Minnesota

3.5.1
Silvicultural Systems

A *silvicultural system* is defined as a management process, following accepted silvicultural principles, whereby stands are tended, harvested, and replaced, resulting in a forest of distinctive form. Included in the silvicultural system are the type of harvest method (clearcutting or individual tree selection, etc.), site preparation (mechanical scarification, prescribed burning, etc.), and regeneration (planting, seeding, or natural regeneration) practices. The two major management methods in forests are even-aged and uneven-aged management.

Even-aged Management

Even-aged management is the application of a combination of actions that results in the creation of stands in which trees of essentially the same age grow together.

Clearfelling

To avoid confusion, clearfelling is used instead of clearcutting as the general term depicting the removal of all trees from an area in one cut to produce an even-aged stand. Clearfelling usually yields the highest merchantable volume growth per acre, and has the lowest per unit volume harvesting cost. It is also the most feasible silvicultural system for most shade intolerant species (i.e., unable to regenerate and grow under the shade of others). There are a number of forms of clearfelling:

Clearcutting.—Any clearfelled area which is greater than or equal to 5 acres.

Clearcutting with standing residuals.—Any clearfelled area which is greater than or equal to 5 acres with 6 to 9 live and/or dead residuals left standing per acre.

Block cutting.—Any clearfelled area less than 5 acres which is regular (usually square) in shape.

Patch cutting.—Any clearfelled area less than 5 acres which is irregular in shape. Patch cuts are generally more aesthetically pleasing than block cuts.

Alternate strip cutting.—A clearfelled area generally at least the width equal to the tree height, and as long as the effective off-road transport distance for the conditions present (generally less than 1,200 feet), with leave strips left between cut strips.

Shelterwood

The shelterwood system requires two (i.e., two-stage shelterwood) or more cuts before the final harvest. The initial cuts are used to stimulate reproduction through increasing seed production, stimulating stump and/or root sprouting, and supplying increased light to the new seedlings, sprouts, or advanced regeneration. The remaining stems provide shelter from excessive fluctuations in temperature (e.g., frost) and moisture (e.g., water stress) and, in some cases, insect pests. Once the stand is regenerated, the sheltering trees are removed. In the shelterwood system more than 20 dominant trees per acre are left after the initial cut.

Seed Tree

Seed tree cutting is similar to shelterwood cutting, except fewer trees are left per acre. Seed trees can be left evenly distributed over the cutover or in groups. The number of seed trees left depends on the species and can vary from 10 to 20 dominant, good quality trees per acre. Once sufficient seedling stocking is reached, the seed trees are removed.

Thinning

Thinning is not a silvicultural system, but an intermediate cutting in an even-aged stand used to increase diameter growth on the remaining stems, salvage natural mortality, reduce the rotation age, increase stand quality and hygiene, increase the content of more desirable species within a stand, and, in some cases, allow the more successful use of shelterwood and seed tree methods (e.g., trees become more *wind-firm*). Thinning may be from below (favor dominant trees) or above (favor most promising trees, not necessarily dominant trees). Thinning may be selective, in which individual trees, usually poor quality or suppressed trees, are removed from throughout a stand, and row thinning where every second or third row of a plantation is removed.

Uneven-aged Management

Uneven-aged management is the application of a combination of actions needed to simultaneously maintain continuous high forest cover, recurring regeneration of desirable species, and the orderly growth and development of trees though a wide range of diameter and age classes, preferably in all age and diameter classes within a rotation. This is the silvicultural system which requires the most planning, tree selection, and harvesting skill. This silvicultural system is most applicable to shade tolerant species (i.e., can grow under the shade of other trees). Two methods of logging can be used in uneven-aged logging:

Individual (single) tree selection logging.—Individual trees are selected for removal uniformly throughout the stand due to overmaturity, poor hygiene, poor form, or some other selection criterion.

Group selection logging.—Groups of 3 to 4 overstory trees, as well as any understory trees beneath them, are removed throughout a stand to produce a patchwork pattern. Depending on the size of the opening, this system could also be classed as patch cutting.

Uneven-aged management is likely to be used more in the future as harvesting and management become more sensitive to broad social and ecosystem values, especially aesthetics and biodiversity. However, it is easily misused to become just high grading (i.e., selecting mainly the best trees for removal), thus reducing the quality of the local genetic pool and the overall quality of the stand. It also limits genetic improvement opportunities. Further, if not done with great care, damage to residual stems can lead to a decline in stand health. The system also involves frequent access (typically removals are spaced at 10- to 20-year intervals).

3.5.2 Harvesting Systems and Methods

A *harvesting system* is the tools, equipment, and machines used to harvest an area. This includes some machinery to fell trees, delimb them if necessary, and off-road transport to a road where the logs can be trucked to a mill. Felling is commonly by chainsaw or feller-buncher, a machine resembling a construction crane with a boom capable of cutting trees at the base, picking them up, and laying them on the ground in small bunches. Common transport methods are by grapple skidder and cable skidder, both tractor-like vehicles that grab a bunch of logs with a plier-like mechanical arm or with a cable to be dragged to a pick up location.

A *harvesting method* is the form in which wood is delivered to the logging access road. Common harvesting methods in Minnesota include: (1) cut-to-length, in which trees are felled, delimbed, and bucked to the desired length in the stump area; (2) tree length, in which trees are felled, delimbed, and topped in the stump area or a point before roadside; (3) full tree, in which trees are felled and transported to roadside with branches and top intact.

3.5.3 Silvicultural and Harvesting System Use in Minnesota

Of the total timber harvested in Minnesota during 1991, 39 percent of the volume is estimated to have come from clearcuts and 42 percent from clearcuts with standing residuals. Clearcutting with standing residuals is the practice of leaving 6 to 9 live or dead standing stems per acre. The two categories in turn accounted for 71 percent of the area with logging operations. The percent area subject to clearcutting or clearcutting with residuals ranged from 56 percent on private and other lands, to 91 percent of forest industry lands (table 3.14). Patch, strip, and other modified clearcutting accounted for 8 percent of the volume and area logged. Selection cutting accounted for 5 percent of the volume and 8 percent of the area logged. The volume removed in thinnings was 4 percent, and this occurred on 10 percent of the areas with logging operations.

The total area with logging operations in 1991 was estimated to be 199,828 acres. Regeneration by planting occurred on 32,603 acres, seeding on 5,963 acres, and natural regeneration on 142,275 acres. Approximately 10 percent was thinned and required no regeneration or site preparation. Therefore, virtually all harvested areas are retained in or will be regenerated to a forested condition. On 28,509 acres where site preparation did take place, 63 percent was mechanical preparation, 29 percent involved chemical herbicide treatment, and 8 percent was by prescribed burning. Of the nearly 200,000 acres harvested, 55 percent was on private and other lands; 8 to 15 percent on each of state, county, and national forests; and 6 percent on private industry lands (table 3.14).

Statewide, the average logging site area was 32 acres. However, since logging operations commonly consist of several cutting units, individual cuts are probably smaller in size. Most logging occurred during the winter (December-February, 43 percent), while the least occurred during the spring (March-May, 9 percent). Logging during the summer (June–August) accounted for 22.5 percent of the volume harvested, while 25.3 percent of the volume was harvested during the fall (September–November).

In northern Minnesota, ecoregions 1 through 4, the majority of the felling (69 to 81 percent, depending on the region) was by feller-buncher. In the Central Pine-Hardwood area of Minnesota (ecoregions 5 and 6), all of the felling reported in the survey was by chain saw. For the state on average, 73 percent of the felling was by feller buncher, 27 percent by chain saw, and less than 0.5 percent by mechanized harvester.

Table 3.14. Summary of estimated annual silviculture operations on timberlands by ownership over the period 1990–91.

DATA SOURCE	Survey					Estimate	Total estimate
OWNERSHIP	State	County	National Forests	Forest industry	Native American	Private & other	
Area of ownership, ac	2,584,000	2,226,506	1,705,000	834,479	498,046	6,023,800	13,871,831
Total volume harvested, cord	685,900	553,071	344,000	214,635	86,692	1,959,002	3,843,300
Area with logging operations, ac	30,861	26,395	17,296	11,148	4,428	109,700	199,828
Natural regeneration area, ac	19,760	20,594	13,113	7,559	3,402	77,847	142,275
Artificial regeneration area, ac	9,465	5,128	2,724	2,765	481	18,003	38,566
SILVICULTURAL SYSTEMS AND THINNING, % by volume							
- clearcutting (area >5ac)	55	60	0	95	93	26	39
- clearcutting with standing residuals	38	29	97	1	0	42	42
- patch cutting (0.25-5ac)	3	5	0	0	0	7	5
- strip or other modified clearcut	1	2	0	0	2	6	3
- seed tree cutting	0	0	0	0	0	1	1
- shelterwood cutting	0	0	0	0	0	3	1
- selective logging	1	3	0	0	0	9	5
- thinning	2	1	3	4	5	6	4
SILVICULTURAL SYSTEMS AND THINNING, %by area							
- clearcutting (area >5ac)	52	56	0	91	83	21	34
- clearcutting with standing residuals	36	30	91	1	0	35	37
- patch cutting (0.25-5ac)	2	5	0	0	0	6	5
- strip or other modified clearcut	1	2	0	0	1	5	3
- seed tree cutting	0	0	0	0	0	1	1
- shelterwood cutting	1	0	0	1	1	5	3
- selective logging	2	5	0	0	0	13	8
- thinning	5	3	8	7	15	13	10
REGENERATION AREAS, acres							
- planting	4,750	4,948	1,979	2,442	481	18,003	32,603
- seeding	4,715	180	745	323	0	0	5,963
- natural regeneration	19,760	20,594	13,113	7,559	3,402	77,847	142,275
- TOTAL	29,225	25,722	15,837	10,324	3,883	95,850	180,841
SITE PREPARATION AREAS, acres							
- chemi-aerial	402	0	0	54	0	399	855
- chemi-ground	1,402	1,369	0	191	0	2,593	5,555
- prescribed burning	825	120	192	100	0	1,083	2,320
- mechanical	3,553	1,360	2,431	1,831	444	8,421	18,040
- mechanical with band spraying	0	0	0	932	0	816	1,748
- TOTAL	6,182	2,849	2,623	3,108	444	13,313	28,519
TIMBER STAND IMPROVEMENTS, acres							
- chemical release - aerial	535	2,715	0	2,002	0	366	5,618
- chemical release - ground	675	1,877	0	1,362	0	273	4,187
- hack and squirt	20	0	0	0	0	1	21
- mechanical/manual release	808	455	3,782	53	408	383	5,889
- noncommercial thinning	427	164	60	203	590	172	1,616
- residual stem felling	570	271	7,686	474	0	1,071	10,072
- pruning	150	28	13	10	0	24	224
- slash disposal (burn brush piles)	50	41	0	0	0	11	102
- TOTAL	3,235	5,550	11,541	4,104	998	2,301	27,729

Source: Jaakko Pöyry Consulting, Inc. (1992m).

The majority of the delimbing was done manually using a chain saw (66 percent), while 33 percent was delimbed using mechanized equipment. In addition, 68 percent of the delimbing and topping was in the cutover, while less than 32 percent was at roadside. Less than 1 percent of the volume was full tree chipped. In general, chain saws are used to delimb hardwoods in the cutover, while mechanical delimbing is used more in softwoods and occurs mainly at roadside. There was also a minor amount of mechanical delimbing in the cutover.

Off-road transport of wood was mainly by grapple skidder (69 percent of the volume harvested). Off-road transport by cable skidders accounted for 30 percent. Grapple skidders were most widely used in northern Minnesota, while cable skidders were most used in the Central Hardwood portion of the state. The average age of logging equipment in Minnesota is high with the majority (64 percent) of all equipment being greater than six years old.

The majority of the bucking occurred at roadside (76 percent). Only 7 percent of the wood was bucked in the cutover. Almost 17 percent of the wood was not bucked and was transported to the mills as tree lengths. Less than 1 percent of the volume harvested was full tree chipped. The majority of the full tree chipping was of hardwood residuals destined for hog fuel.

Transport of wood from roadside to the mills is by truck. Less than 1 percent of the volume transported was in chip form. Approximately 82 percent of the volume was transported in pulpwood or log lengths, while 17 percent was as tree lengths. Almost all wood was transported by tractor-semitrailer units, with an average load capacity of about 10 to 11 cords Tandem axle trucks with pup trailers are also used to some extent.

3.6
Utilization of Recycled Fiber

3.6.1
Current and Projected Future Supply of Recovered Paper

Approximately 1.7 million tons of various grades of paper were generated and 0.6 million tons were recovered in Minnesota in 1990, yielding an overall recovery rate of 36 percent. This was slightly higher than the average for the Midwest for most grades.

Approximately 115 thousand tons of old newspaper (ONP) were recovered in 1990 in Minnesota. This recovery is expected to rise to 140 thousand tons by 1995, and 160 thousand tons (or 72 percent of the ONP available) by the end of the decade. Higher future recovery of ONP will mainly be due to new Canadian demand for ONP, good access to supplies in Minnesota, and by mandatory recycling which is monitored and enforced in the U.S. The U.S. recycling programs calling for increased recycled paper content in U.S. newsprint are providing recovered material (e.g., ONP) for Canada to meet U.S. demand for newspaper. However, most of the current ONP collected in Minnesota (e.g., in 1990) was used by Minnesota mills; and the net surplus demand totaled only 20 thousand tons (which went primarily to Canada). The net state surplus is expected to rise to 40 thousand tons by 2000.

About 30 thousand tons of old magazines (OMG) were collected in Minnesota in 1990. The majority of the OMG collected in Minnesota was overissue or newsstand returns. Recovery is expected to rise 40 thousand tons by 1995 and 55 thousand tons by 2000. None of the OMG collected in Minnesota is used in Minnesota mills. This is not expected to change throughout the decade.

An estimated 50 thousand tons of office wastepaper (OWP) in Minnesota were recovered in 1990. By 1995, recovery is expected to rise to 100 thousand tons and to 120 thousand tons by 2000.

3.6.2
Demand and Use of Recovered Paper Now and in the Future

Overall, mills in Minnesota consumed 15 thousand tons more OWP than was collected in the state in 1990. Because of the various subgrades (i.e., computer printout, white grades, mixed), some grades are likely to be shipped out of Minnesota, while other grades are imported. The net deficit, however, is expected to increase as two planned deinked pulpmills come online in Minnesota in the 1990s. By 2000, mill consumption will likely exceed collection by about 130 thousand tons.

Increased collection and use of recovered paper in Minnesota and surrounding states could reduce demand for wood by the state's forest products industry, but supplies of some grades are limited. The state's paper industry is mainly comprised of printing and writing paper mills. Most of the pulp consumed is bleached kraft (chemical) and groundwood pulps.

The alternative recovered papers for bleached virgin kraft pulp include high-grade deinking, pulp substitutes, or OWP. Planned use of OWP by two new market deinked pulpmills in Minnesota would yield a net shortfall of this grade within the state. Note that market pulpmills are those that manufacture pulp for sale in the open market.

Recovered papers that represent the most realistic alternatives to bleached virgin groundwood pulp are ONP and OMG. Users of these grades compete with Canadian newsprint mills for limited supplies. Canadian mills have already established long-term contracts for ONP collected in Minnesota. Supply contracts for these grades from Canadian newsprint mills would limit the availability of ONP and OMG to new users. The inconsistent quality of mixed paper currently precludes its use in significant quantities to make printing and writing papers.

3.6.3
Potential Expansion of Recycled Fiber Utilization and Effects on the Wood Products Industry

The effect increased collection and use of recovered paper will have on the wood products industry will depend on the type of pulp it replaces. Economics favor the substitution of recovered paper for purchased pulp rather than integrated pulp, if substitution for integrated pulp means idling existing facilities. Integrated pulp is that manufactured at a facility where the pulping operations are colocated (integrated) with the papermaking, such as the Potlatch Corporation mill at Cloquet. If recycled pulp made from recovered paper replaces purchased pulp, there would be little or no effect on the wood harvest in the state since the purchased pulp being replaced is not a product of the Minnesota's forests. Recycled pulp could replace planned virgin pulp capacity. Planned increases in virgin pulping capacity at Minnesota paper mills by 1995 total almost 600 thousand tons, which will require an additional 1.1 million cords/year. Some Minnesota paper mills purchase kraft pulps to augment integrated kraft pulp production or as an exclusive kraft source. All groundwood consuming mills in the state are integrated to groundwood pulp.

Under the following specific conditions, use of market deinked pulp produced in Minnesota could replace up to 400 thousand cords of wood harvested in the state annually:

- if the recycled pulp produced by Superior Recycled Fiber Industries (a mill now under construction) offsets planned virgin chemical pulp capacity of Minnesota mills, it could reduce demand for wood by up to 150 to 200 thousand cords per year; and
- if the planned recycled pulp produced by Minnesota Pacific Pulp and Paper Corporation is built and then offsets planned chemical pulp capacity of Minnesota mills, it could reduce annual demand for wood by up to 150 to 200 thousand cords.

Given the configuration of the state's pulp and paper mills, it is unlikely that market deinked pulp will replace *existing* virgin pulp production in Minnesota. The factors supporting this conclusion include the composition of the state's paper industry, the economics of replacing existing pulp production, the physical characteristics of deinked pulp versus currently used pulps, and the supply and demand for OWP. The most likely scenario is for market deinked pulp to substitute for additional virgin pulp capacity first, and then to replace purchased kraft pulp. However, these two scenarios are not exclusive, and a combination of the two could exist simultaneously.

3.7 Impacts of Global Climate Change on Minnesota's Forests

Emissions of CO_2, caused mainly by fossil fuel burning, and other greenhouse gases, are likely to enhance the earth's natural greenhouse effect, causing significant warming over the next century. Global circulation models (GCMs) are computer models of the earth's atmosphere capable of simulating the earth's current climate, including seasonal changes. Several GCMs produced by independent teams of scientists agree that an increase in the mean air temperature at the earth's surface of 1.5° to 4.5°C will result if the concentration in the atmosphere of CO_2 doubles ($2xCO_2$ scenario). The length of time required for atmospheric CO_2 concentrations to double will depend on the rate at which people reduce the use of fossil fuels, but may occur sometime between the years 2030 and 2100. Current versions of GCMs have poor spatial resolution. However, preliminary results suggest that interior continental areas such as Minnesota may warm more than the global average. Although estimates of precipitation are still very uncertain, a majority of the five GCMs surveyed for this report predict that Minnesota will have decreased summer soil moisture under $2xCO_2$ scenarios. On the other hand, a majority also predict increased winter soil moisture, which could partially compensate for drier summers.

Should significant warming occur in Minnesota, a northward shift in vegetation types such as the prairie-forest border is likely, so that the state will have less forest acreage in the future. The warm period, 7,000 years before the present (ybp), when temperatures of the current interglacial period reached their peak in the Midwest, provide a reasonable analog for future warming. Summer temperatures at that time were 1 to 2°C warmer than at the present time, and the prairie-forest border was located about 100 miles to the northeast of its current location.

Several different speculative simulations of response of forests to warming agree in general with the altithermal analog. Empirical models that look at the climate at the edge of the current range of a species or vegetation type and project where the same limiting climate variables would occur under $2xCO_2$ scenarios, predict significant displacements in species ranges. The predicted geographical displacements vary with the GCM used. For example, the western edge of the sugar maple range would only move a few tens of miles eastward under the GISS GCM $2xCO_2$ scenario, which predicts increased rainfall in Minnesota. The increased rainfall would compensate for the warmer temperatures. However, under the GFDL $2xCO_2$ scenario, the southwestern edge of the sugar maple range would move north of Lake Nipigon, Ontario. Forest stand dynamic models predict that under a $2xCO_2$ scenario, spruce-aspen-birch forests in northern Minnesota will change to sugar maple forest on deep loamy soils, or pine/oak savanna on shallow and/or sandy soils. If significant warming occurs, the overall predicted patterns are for southern Minnesota forest types to displace northern types, and southern forest types to be displaced by grassland.

Depletion of ozone in the earth's stratosphere is another factor that may exacerbate the effects of global warming. With a thinned ozone layer, more ultraviolet light than usual may impinge on forest canopies, possibly causing physiological damage to trees and reducing productivity.

Air pollution is unlikely to cause significant damage other than very locally near point sources of pollution. Although eastern Minnesota has rainfall slightly more acidic than natural rainfall, the state is outside the area with rainfall pH low enough to cause long-term significant forest damage. Levels of ozone, nitrogen oxides and sulfur dioxide are not high enough to cause widespread forest damage in Minnesota.

There are several factors that will influence the rate and magnitude of change in forests that are difficult to simulate. Theoretically, increased concentrations of CO_2 should have direct effects on plant growth, making them more efficient in water use, thereby compensating for drought stress brought on by warmer temperatures. Research on direct CO_2 effects is in early stages, and there are conflicting results among studies as to whether there will actually be a significant compensatory effect. Warmer summer weather could increase the frequency of severe wildfires and windstorms, accelerating the rate of change in forest species composition. Climatic warming will probably not proceed evenly over time, but instead will follow the natural tendency towards periods of several very warm years in a row, alternating with periods of less warm years (serial correlation). This could lead to periods with extremely severe fire weather and high heat or drought induced mortality. Other factors that could modify the response of forests to global change include changes in pest-host relationships, changes in seasonal distribution of precipitation, the currently unknown ability of individual trees to tolerate changes in climate, and the ability of trees to shift their range northward at rates much faster than those that have occurred due to natural climate change over the last 20,000 years. No one simulation of forest response to climatic change takes all of these factors into account, but there are models that take some into account individually.

Forest management activities add another unknown element to global change. The movement of vegetation now depends on both natural and human vectors. Extensive tree planting, fire control, and development of drought-tolerant varieties can lead to establishment of forests outside a species' current or future natural range. In addition, the Minnesota forest products industry and public land managers could respond to global warming by altering spatial and temporal patterns of harvest. For example, stands with high heat-induced mortality could be harvested and reforested with species adapted to a warmer climate. These activities could compensate—to an unknown degree—for the effects of global change on Minnesota forests.