Status and Trends of Silvicultural Practices in Minnesota

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ABSTRACT: *This article describes the kind and extent of silvicultural practices applied in Minnesota. We surveyed land managers with respect to silvicultural systems and practices employed during 1996. Results were compared to corresponding information from 1991. The study obtained input from ownerships covering approximately 50% of the acreage and timber volume harvested in the state. The statewide harvest volume increased 8% from 1991 to 1996, and the estimated acreage subject to harvesting increased 1%. An increased emphasis on thinning was a significant factor in the rise in total acreage harvested. From 1991 to 1996, clearcutting (> 5 ac) decreased from 89 to 85% of the acreage harvested. Residuals were left on 77% of the acreage clearcut, a level nearly twice as high as in 1991. Reliance on natural versus artificial regeneration increased by 7% since 1991. At the same time, artificial regeneration efforts showed greater emphasis on site preparation rather than later release, especially on land owned by forest industry. Overall, forest management trends in Minnesota are moving toward a more intensively managed but also more diverse forest across ownerships. North. J. Appl. For. 16(4):203–210.*

In 1990, Minnesota initiated a Generic Environmental Impact Statement (GEIS) on timber harvesting and forest management (Jaakko Pöyry Consulting Inc. 1994). Part of that study collected and summarized basic information about silvicultural practices in Minnesota (Jaakko Pöyry Consulting Inc. 1992a). A broad assessment of silvicultural practices and trends can help policy-makers, forest managers, the forest industry, and others concerned about forest ecosystems (Fajvan et al. 1998). This study provides an update on silvicultural practices since the GEIS study. A comparison of the 1996 information with silvicultural practices in 1991 is a basis for investigation of current trends in forest management.

History of Silviculture Practices

Silviculture practices are determined in part by the forest composition (see Leatherberry et al. 1995). Forest composition is very dynamic and influenced by historical developments (Stearns 1997), including climate patterns (Clark 1990), natural disturbances (Heinselman 1996), and harvesting and forest management activities (e.g., Larson 1972). In the early 1800s, Minnesota's forest area was 31.5 million ac and was dominated by conifers. White pine was the species most heavily logged between 1880 and 1910 (Jaakko Pöyry 1992b, Larson 1972). Later, logging of white pine declined and then moved to other species, particularly other conifers and the larger hardwoods. The forest harvest reached a low point in the mid-1930s and remained roughly stable until the 1960s. Since then, the trend in forest harvesting has been gradually upwards.

Early land speculation and settlement led to much of the state falling into private ownership, primarily farmland. This began to change first with the establishment of the National Forests and then State Forests early in this century. In the 1930s and 1940s, large-scale tax forfeiture occurred, and public agencies acquired privately owned lands that were no longer viable as farmland. Importantly, lands considered viable for agriculture at one time usually had a higher productivity level, compared with federal lands, as most of these never supported agriculture. Private owners generally retained the most productive agricultural land (and timberland) concentrated in south, central, and northwestern Minnesota, while land with lower agricultural productivity was forfeit. At first, state and county agencies did not have the personnel or funding at the time to manage the tax forfeited lands that came under their jurisdiction. Consequently, many of these acres gradually reverted to forest naturally. Portions of individual farms, in total comprising large acreages, also reverted to forest. This new forest was largely even-aged hardwoods and had a large component of aspen, a pioneer species.

Most hardwood stands originated since the 1920s with the initiation of organized fire control. Many conifer stands originated from residuals after earlier logging of softwoods. The age class distribution of conifers is less concentrated than hardwoods because of earlier harvesting and steadier markets

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up to the middle of this century. In addition, many acres have been cut several times, first for pine sawlogs, then for spruce or hardwoods and, more recently, for aspen pulpwood. Thus, the choice of current silvicultural practices in northern Minnesota is determined by the predominantly even-aged nature of the northern forests, the dominance of pioneer species, pulpwood demand, and logging costs.

Early silviculture practice (circa 1900) was geared to restoration of forestlands and focused on regeneration practices, involving mainly white and red pine (Frothingham 1914, Woolsey and Chapman 1914). Research since the 1930s has led to regeneration and other management guides for most commercial species and covertypes [e.g., see Appendix 1 of Jaakko Pöyry Consulting, Inc. (1992a) for information on these guidelines].

Surveys of Practices

The survey of forestland managers in Minnesota was developed and administered during the spring of 1997. Each questionnaire was accompanied by the pertinent silviculture definitions developed by the Society of American Foresters (Society of American Foresters 1994), and it solicited information about operations during 1996. Survey questions were similar to those used in the 1991 survey compiled for the GEIS (Jaakko Pöyry Consulting, Inc. 1992a). Each survey contained sections for background information, harvesting or silvicultural practice, and open-ended questions. Some questions used from the 1991 survey were revised to clarify their intent. New questions were added to facilitate collection of other information. More information on the survey is available in Puettmann et al. (1998a).

The questionnaires were distributed in April 1997 to timberland owners (two state agencies, 13 counties, two national forests, six forest industry firms, and seven Native American bands). As in the 1991 survey, nonindustrial private forest (NIPF) landowners, who own almost half the timberland in Minnesota, were excluded because a comprehensive address list was not available and there were doubts that landowners would know the needed details of silvicultural and harvesting practices on their lands. Telephone followup was employed to increase the silviculture survey response rate.

Because the 1996 respondent pool was very similar to the 1991 survey (the surveys were mailed to the same ownership pool and the acreage managed by the survey respondents differed by less than 1%), the survey data were summarized to compare 1996 and 1991 survey results, primarily in terms of percent. Since state and industry personnel are also involved in management of NIPF land, we also tried to obtain information about the silvicultural practices used on these lands. However, the responses were not complete or detailed enough to allow more than anecdotal comparison of NIPF results with state and industry practice. Most comments indicated that management on NIPF land was similar to management on land owned by the employer of the respondent. However, these responses are limited to NIPF ownership under active management and may not be representative for NIPF ownerships as a whole. Thus, extrapolation of survey responses to statewide estimates (including NIPF ownerships) is only attempted for harvesting activities, for which independent statewide harvest volumes estimates were used to determine the conversion factor.

The estimates of the statewide area with harvesting activity assumed that (1) the relative proportions of harvesting and silvicultural systems used on nonsurveyed land was the same as on land covered by the surveys, and (2) the average volume per acre harvested or treated under each harvesting or silvicultural system did not vary with ownership. While the authors concluded that any deviation from these assumptions was likely to be small, the statewide estimates need to be interpreted with caution. Extrapolation of other silvicultural activities to statewide figures was not attempted.

The survey responses were coded and summarized using Microsoft Excel®. Figures and tables were then developed to aid in editing, understanding the data, and for reporting Standard cords were the volume measurement unit used in the survey and analysis.

While the 1991 and 1996 surveys overlapped substantially in terms of their questions and respondents, no statistical comparison was possible. Instead the results were presented as observations, compared to data from an independent survey of loggers (Puettmann et al. 1998a), and general trends are discussed. Because of privacy concerns, the survey responses were only identified by a code, rather than by owner. Also, to keep the survey forms from becoming overwhelming, we did not collect data broken down by forest type. This prevented spatially referencing the responses and precluded the breakdown of the analysis by region or forest cover types.

Results and Discussion

Survey Coverage

Twenty-five respondents completed the silviculture survey questionnaire. These respondents represented 100% of state and federal land; 92% of county, 50% of industrial; and 86% of Native American ownerships (n = 2, 2, 12, 3, and 6, respectively). In addition, two surveys were incomplete and thus not included in the database.

The silviculture survey questionnaires asked for the source of information, i.e., whether the numbers reported were directly from a database or whether they were estimates. Obviously, the databases varied between timberland owners Some owners provided estimates to all questions, while others (e.g., federal and state ownerships), have a formal database with sufficient detail to answer most questions directly.

The acres reported as harvested with different silvicultural systems were typically documented in the landowner databases, but the size class distribution of the clearcuts was mostly estimated. Also, few respondents had information about the specific acreage with regeneration, site preparation, and release in their databases. In particular, the area regenerated through natural regeneration was poorly documented. As expected, the proportion of different slash treatments as well as the seasonal distribution of harvests were mostly estimated. State and federal owners

Table 1. Summary of 1996 silvicultural survey response for acreage and volume harvested

	No. of respondents	Reported	Respondent Min	Respondent Max
Timberland (ac)	25	7,720,204	5,400	2,600,000
Total volume harvested (cords)	25	1,965,164	1,474	533,000
Fuelwood (cords)	25	63,468	50	20,000
Average clearcut (ac)	25	24	6	50
Average partial cut (ac)	21	27	3	200
Total area in silvicultural systems (ac)	25	99,297	126	41,546
Cords harvested/ac timberland		0.25		
Cords harvested/ac logging activity		19.8		

have written standards for "residuals" in clearcuts, and many organizations keep records of the area "clearcut with residuals." However, respondents could provide only an estimate of the number of trees left behind, their spatial distribution, and so on.

Because the respondent pool and the acreage covered by the silviculture survey was similar (1% smaller) to the 1991 survey (Jaakko Pöyry Consulting, Inc. 1992a), the data obtained for 1996 are comparable to 1991 survey responses. The following discussion focuses on this comparison, but is limited to land holdings of those that responded to both surveys. However, any interpretation should consider the special circumstances that influenced forest management during 1991 or 1996. One major factor listed by the respondents was the July 1995 windstorms, which resulted in considerable salvage harvesting during 1995 and 1996. Also, because many estimates presented are based on tabulating responses that were themselves estimates, small changes need to be interpreted with caution.

Table 1 indicates the respondents' ownerships cover a total of 7,720,204 ac, approximately 52% of the 14,723,200 ac of timberland in the state (Leatherberry et al. 1995). A volume of 1.97 million cords was harvested from timberland managed by the survey respondents. This figure was 51% of the 1996 statewide harvest of 3.81 million cords tabulated by Krantz (1998)[1] (see Table 2). The overall harvest level in the state grew 8% from 3.53 million cords in 1991 to 3.81 million cords in 1996 (Krantz 1998). The harvest volume removed per acre timberland (0.25 cords) and per acre with harvesting activity (19.8 cords) were similar to the harvest volumes in 1991 (0.24 and 20.6 cords, respectively).

Table 2 also presents statewide estimates for harvest area and silvicultural systems. Note that the results for the 1991 survey have been updated to reflect the statewide timberland acreage from Leatherberry et al. (1995). Also, the estimates of harvest for 1991 have been adjusted to those provided by Krantz (1998). Of special note is that fuelwood cut from growing stock is included in these harvest figures. In 1991 this fuelwood was estimated as 530,000 cords. In 1996, the fuelwood component is estimated at 200,000 cords (Krantz 1998).

The statewide estimates for 1996 were calculated as simple expansions of the figures reported by respondents (i.e., this approach assumes the harvest per acre by silvicultural system and the proportional application of silviculture systems was the same on surveyed and nonsurveyed land). The expansion factor used throughout was the statewide harvest divided by the respondent reported harvest, 3,810,000 ÷ 1,965,164 = 1.93877. Adjusted estimates for 1991 were calculated in a similar manner. The resulting expansion factor for 1991 was 3,530,000 ÷ 1,858,849 = 1.89902. An alternative expansion factor can be derived from statewide timberland acreage divided by respondent acreage (e.g., 14,723,200 ÷ 7,720,204 = 1.90710), but the difference between this factor and that based on volume is small. Further, in this study, volume reporting was based on consumer surveys and considered

[1] J. Krantz, facsimile communication of 1996 harvesting and utilization survey data based on consumer survey. Minnesota Department of Natural Resources, Division of Forestry, January 8, 1998.

Table 2. Silviculture questionnaire results for Minnesota, 1996 and 1991. The statewide estimate is an extrapolation based on volume harvested from surveyed and nonsurveyed land and needs to be viewed with caution.

Variable	Survey results 1996	Survey results 1991	Statewide estimate 1996	Statewide estimate 1991
Ownership, harvesting, and regeneration				
Timberland ownership (ac)	7,720,204	7,848,031	14,723,200	14,723,200
Total volume harvested (cords)	1,965,164	1,858,849	3,810,000	3,530,000
Harvesting operations (ac)	99,297	90,128	192,514	171,155
Natural regeneration (ac)	69,220	64,428	134,202	122,350
Artificial regeneration (ac)*	16,566	20,563	32,178	39,050
Silvicultural systems and thinning, ac (percent)				
Clearcut (>5 ac) with or without residuals	84,567 (85)	80,214 (89)	163,956 (85)	152,328 (89)
Patch clearcut	727 (1)	1,803 (2)	1,409 (1)	3,434 (2)
Strip clearcut	234 (0)	901 (1)	454 (0)	1,711 (1)
Seed tree cut	1,356 (1)	0 (0)	2,629 (1)	0 (0)
Shelterwood	789 (1)	0 (0)	1,530 (1)	0 (0)
Selective logging	1,022 (1)	1,802 (2)	1,981 (1)	3,422 (2)
Thinning	10,602 (11)	5,408 (6)	20,555 (11)	10,270 (6)

* Does not include hybrid poplar.

Table 3 Harvesting activities by ownership. Data were derived from the silviculture survey 1996 and represent a total of approximately 50% of timberland in Minnesota. Nonindustrial private forests were not surveyed.

		Ownership				
Variable	Survey total	State	County	Federal	Industry	Native American
Ownership, harvesting, and regeneration						
Area of ownership (ac)	7,720,204	2,605,400	2,543,909	1,206,147	838,000	526,748
Total volume harvested (cords)	1,965,164	554,094	618,427	324,580	360,181	107,882
Area with logging operation(ac)	99,297	41,914	26,883	15,106	9,839	5,555
Natural regeneration area(ac)	69,220	22,080	21,851	11,488	8,777	5,024
Artificial regeneration area(ac)*	16,566	7,645	3,017	1,835	3,215	854
Silvicultural systems and thinnings by ownership, ac (%)						
Clearcutting >40 ac	23,149 (23)	5,270 (12)	8,157(30)	1,625 (11)	6,114 (62)	1,983 (36)
Clearcutting 20–40 ac	42,189 (43)	24,000 (57)	7,377(27)	6,907 (46)	2,107 (21)	1,798 (32)
Clearcutting 6–19 ac	19,229 (19)	5,118 (12)	7,852(29)	4,195 (28)	1,318 (13)	746 (13)
Patch clearcutting	727 (1)	0 (0)	246 (1)	0 (0)	50 (1)	431 (8)
Strip clearcutting	234 (0)	0 (0)	184 (1)	0 (0)	0 (0)	50 (1)
Seed tree	1,356 (1)	494 (1)	817 (3)	0 (0)	0 (0)	45 (1)
Shelterwood	789 (1)	62 (0)	546 (2)	181 (1)	0 (0)	0 (0)
Single tree selection	612 (1)	93 (0)	339 (1)	0(0.0)	30 (0)	150 (3)
Group selection	410 (0)	347 (1)	0 (0)	0(0.0)	0 (0)	63 (1)
Thinning	10,602 (11)	6,530 (16)	1,365 (5)	2,198 (15)	220 (2)	289 (5)
Residuals, ac (%)						
Clearcut > 5 ac with or without residuals	84,567 (85)	34,388 (82)	23,386 (87)	12,727 (84)	9,539 (97)	4,527 (81)
Clearcut > 5 ac with residuals	64,735 (77)	27,170 (79)	19,490 (83)	12,090 (95)	3,276 (34)	2,709 (60)
Percent residuals alive	(87)	(80)	(81)	(85)	(90)	(85)
Percent ac with residuals scattered	(67)	(57)	(72)	(82)	(75)	(60)

* Does not include hybrid poplar.

more reliable than acreage information, and use of volume-based expansion guarantees consistency with the known statewide harvest. Silvicultural systems data were expanded statewide by the same factors as volume. Regeneration, site preparation, timber stand improvement and other silvicultural activity data were not expanded statewide because they were perceived to be less precise than total harvest and silvicultural systems data, and because independent estimates of statewide activities did not exist. However, respondent acreage data on these activities allows identification of relative levels of activity and trends.

Based on the 1996 survey, the estimated area with harvesting activity (192,514 ac) was 11% greater than in 1991. While on national forest lands, regeneration harvest activity declined by 19% between 1991 and 1996, the increased harvest area is partially due to thinning activity on federal and state ownerships (see Tables 3 and 4). However, for the same volume of wood, thinning results in harvesting more acres than would be the case with clearcutting. For example, Jaakko Pöyry Consulting, Inc (1992a) noted removal volumes of 21.6, 17.2, 8.6, 11.9, and 8.8 cords/ac in harvests by clearcuts, seed tree cuts, shelterwood cuts, selective cuts, and thinning, respectively.

Table 4. Acres or proportion of silvicultural systems and thinning by ownership. [Part of Table 4.1 in Jaakko Pöyry Consulting, Inc (1992a)]. Data were derived from the silviculture survey 1991 and represent a total of approximately 50% of timberland in Minnesota. Nonindustrial private forests were not surveyed.

		Ownership				
Variable	Survey total	State	County	Federal	Industry	Native American
Ownership, harvesting, and regeneration						
Area of ownership (ac)	7,848,031	2,584,400	2,226,506	1,705,000	834,479	498,046
Total volume harvested (cords)	1,858,849	685,900	553,071	344,000	214,635	86,692
Area with logging operation (ac)	90,128	30,861	26,395	17,296	11,148	4,428
Natural regeneration area (ac)	64,428	19,760	20,594	13,113	7,559	3,402
Artificial regeneration area (ac)	20,563	9,465	5,128	2,724	2,765	481
Silvicultural system and thinning by ownership (% of total ac)						
Clearcutting > 5 ac*						
without residuals	50	52	56	0	91	83
with residuals	39	36	30	91	1	0
Patch clearcutting	2	3	5	0	0	0
Strip clearcutting	1	2	2	0	0	1
Seed tree	0	0	1	0	0	0
Shelterwood	0	1	0	0	1	1
Selection cutting	2	2	5	0	0	0
Thinning	6	5	3	8	7	15

* Clearcuts were not separated by size class in 1991.

Silvicultural Systems

Overall, the relative proportions of the various silvicultural systems and thinning activities changed little between 1991 and 1996 (see Table 2). Clearcutting (> 5 ac) is still the dominant silvicultural system. The proportion of clearcut land declined only marginally from 89 to 85%. An independent survey of 390 loggers operating in Minnesota during 1996 showed a similar trend (Puettmann et al. 1998a). According to the loggers surveys, 80 and 76% of the volume was harvested under clearcutting in 1991 and 1996, respectively. Clearcutting was the predominant silviculture system used for all timberland ownerships (Tables 3 and 4). The average clearcut size is 24 ac, and the average partial-cut size (acreage in sale) was 27 ac (Table 1). Both these values are very similar to the 1991 survey. Weighting by the total area cut by each respondent, the average partial cut size falls to 23 ac, while the average clearcut size remains unchanged. Drawing from Table 3, 62% of the area clearcut on industry land was in clearcuts greater than 40 ac. Clearcut sizes between 20 and 40 ac were most common on state and federal land. Clearcut sizes on county land were evenly split between clearcuts greater than 40 ac, 20 to 40 ac, and 5 to 20 ac. The amount of acres harvested by patch, strip, seed tree and shelterwood, group selection, and single tree selection accounted for only a small proportion of the area logged in 1996.

Clearcut with Residuals

Compared to the 1991 survey, the 1996 survey asked more detailed information about the condition of clearcuts after harvesting. Table 3 shows residuals (trees left in a clearcut for reasons other than regeneration) were left on 77% of the acres clearcut. This proportion is almost twice as high as in 1991. This shift can be attributed largely to changes in the management of public, especially federal land. For example, respondents indicated the acreage on which residual stems were felled dropped from 9,001 in 1991 to 361 ac in 1996 (Tables 5 and 6).

The definition of a clearcut with residuals is not consistent across ownerships. While the Minnesota Department of Natural Resources (DNR) and USDA Forest Service have written standards, others do not have formal criteria. Overall, respondents indicated the average site had 14 trees/ac left as residuals, but the density of residuals varied tremendously with site and species. Because of the various standards and the diversity of forest conditions in Minnesota, sites labeled "clearcuts with residuals" might be hard to distinguish from partial cut sites (Puettmann et al. 1998a).

Most residuals (87%) were alive at the time of harvesting (see Table 3). However, several respondents noted that approximately 10% of the residuals die in the first few years after harvesting. The residuals were generally scattered throughout the site (67% of the acres with residuals) rather than being associated in clumps (33%). Most commonly, residual trees were left for wildlife habitat and as a riparian buffer. Other reasons included visual quality, seed production, nonmerchantability or immature trees, poor markets, public relations, Best Management Practices (BMPs), and species diversity. Most respondents indicated that all these concerns were considered within their organization, but priorities varied by site.

Thinning

Table 3 indicates 16% of the area with harvesting operations on state land were thinned, followed by 15% on national forests, 5% on county, 5% on Native American, and 2% of forest industry land. The increased emphasis on commercial thinning compared to the 1991 survey (Table 4) is paralleled by a doubling of noncommercial thinning activities to 3,055 ac (see Table 5). While commercial thinning increased on public land, the main increase in noncommercial thinning was on land owned by forest industry respondents (2,751 ac, compared to 203 ac in 1991; Tables 5 and 6).

Regeneration

A total of 86,143 ac were regenerated during 1996 (Table 5). The discrepancy between the number of acres on which a regeneration harvest took place and the area with regeneration (e.g., 9,839 ac versus 11,992 ac on industrial forestland) is due to the time lag between the two activities. Most sites regenerated in 1996 were harvested in 1995, and the July 1995 windstorm may have resulted in higher than average regeneration efforts in 1996. A trend to rely more on natural regeneration (69,220 ac of natural seeding and sprouting, a 7% increase over 1991) rather than artificial regeneration (16,566 ac for planting and seeding, a 19% decrease) was evident on all but federal lands (see Tables 5 and 6). Managers relied on natural regeneration through sprouting or suckering on 62,374 acres (90% of the area with natural regeneration). Regeneration by natural seeding was limited to 6,846 ac or 10% of the natural regeneration acreage.

The amount of artificial regeneration declined from 1991 to 1996, with 21 and 16% fewer acres planted and seeded, respectively. In the 1991 survey, underplanting was not documented separately, so it was not possible to compare this practice with results for 1996 (Table 5). Interest in short rotation-intensive culture increased in the early 1990s. Some evidence of this trend is the planting of hybrid poplar cuttings on 357 ac by forest industry. (Because of the unique nature of the hybrid poplar management and the lack of association with forest harvesting, these acres were not included in the summary calculations in Table 5).

Site Preparation

The delay between site preparation and planting or seeding explains the difference in total acreage with site preparation and other regeneration activities (Tables 5 and 6). While the overall acreages regenerated artificially declined, the area with site preparation activities (13,950 ac) was similar to the acreage in 1991. The decline in site preparation effort on public land was offset by an increase on industrial land. The proportion of the area treated chemically increased to 38%. On land with chemical site preparation, 42% of the acreage received an aerial application of herbicides. Table 5 shows the range in acreage treated among respondents. Aerial application is most common on land owned by forest industry (1,260 ac; see Table 5). Aerial application is cheaper than ground application, but residual overstory trees hinder or eliminate low altitude overflights.

Table 5. Acres of silvicultural practices are by ownership. Data were derived from the silviculture survey 1996 and represent a total of approximately 50% of timberland in Minnesota. Nonindustrial private forests were not surveyed.

		Area by ownership (ac)				
Practices	Survey total	State	County	Federal	Forest industry	Native American
Regeneration						
Planting (total)	11,530	4,061	2,118	1,739	2,958	654
Underplanting	1,957	500	72	1,305	0	80
Seeding	5,036	3,584	899	96	257	200
Cuttings (e.g., hybrid poplar)	357	0	0	0	357	0
Natural regeneration, sprouts	62,374	18,080	20,062	11,438	8,300	4,494
Natural regeneration, from seed	6,846	4,000	1,789	50	477	530
Total*	86,143	29,725	24,868	13,323	11,992	5,878
Site preparation						
Chemical—aerial	2,251	748	243	0	1,260	0
Chemical—ground	3,099	1,040	999	0	1,060	0
Prescribed burning	388	147	19	150	0	72
Mechanical (scarification, etc.)	8,212	2,781	1,133	1,050	2,764	484
Total	13,950	4,716	2,394	1,200	5,084	556
Timber stand improvement						
Chemical release—aerial	3,184	767	574	0	1,843	0
Chemical release—ground	3,138	677	961	0	1,500	0
Hack and squirt release	100	100	0	0	0	0
Mechanical/manual release	4,795	1,133	316	2,685	50	611
Noncommercial thinning	3,055	100	40	0	2,751	164
Residual stem felling	361	300	45	6	0	10
Pruning	339	10	66	33	200	30
Underburning	135	0	0	113	0	22
Total	15,107	3,087	2,002	2,837	6,344	827
Slash disposal						
Untreated, left on site	62,801	20,000	24,771	8,800	5,120	4,110
Piled or windrowed	8,232	2,500	1,945	3,500	200	87
Removed (whole tree skidding)	9,223	2,688	1,634	2,201	2,450	250
Total	80,256	25,188	28,350	14,501	7,770	4,447

* Does not include hybrid poplar.

Table 6. Acres of silvicultural practices are by ownership. [Part of Table 4.1 in Jaakko Pöyry Consulting, Inc. (1992a).] Data were derived from the silviculture survey 1991 and represent a total of approximately 50% of timberland in Minnesota. Nonindustrial private forests were not surveyed.

		Area by ownership (ac)				
Practices	Survey total	State	County	Federal	Forest industry	Native American
Regeneration						
Planting*	14,600	4,750	4,948	1,979	2,442	481
Seeding	5,963	4,715	180	745	323	0
Natural regeneration†	64,428	19,760	20,594	13,113	7,559	3,402
Total	84,991	29,225	25,722	15,837	10,324	3,883
Site preparation						
Chemical—aerial	456	402	0	0	54	0
Chemical—ground	2,962	1,402	1,369	0	191	0
Prescribed burning	1,237	825	120	192	100	0
Mechanical (scarification, etc.)	9,619	3,553	1,360	2,431	1,831	444
Mechanical with band spraying	932	0	0	0	932	0
Total	15,206	6,182	2,849	1,623	3,108	444
Timber stand improvement						
Chemical release—aerial	5,252	535	2,715	0	2,002	0
Chemical release—ground	3,914	675	1,877	0	1,362	0
Hack and squirt release	20	20	0	0	0	0
Mechanical/manual release	5,506	808	455	3,782	53	408
Noncommercial thinning	1,444	427	164	60	203	590
Residual stem felling	9,001	570	271	7,686	474	0
Pruning	201	150	28	13	10	0
Slash disposal (burn brush piles)	91	50	41	0	0	0
Total	25,428	3,225	5,550	11,541	4,104	998

* Includes underplanting.
† Includes natural regeneration from sprouts and seeds.

The acreage with mechanical site preparation declined by 15%. Burning activities are strongly influenced by weather patterns and thus vary tremendously from year to year. Consequently, the decrease in burning activity (see Tables 5 and 6) in 1996 more likely reflects a difference in rainfall during the burning seasons rather than a trend away from using prescribed burning.

Release

The compilation of timber stand improvement efforts in Table 5 shows the amount of regeneration release (11,217 ac) declined by 24% between 1991 and 1996. This decline was evident in all release methods except hack and squirt application, which is rarely done (a total of only 100 ac on state land; Table 5). Reducing release efforts, a trend which is most apparent on county-owned land and, to some extent, on federal land, might suggest more efficient site preparation (with increased use of chemicals) and/or a trend to acceptance of mixed species stands.

Other Silvicultural Issues

Respondents indicated harvesting operations occurred primarily during the winter (54%) followed by summer (21%), fall (16%) and spring (8%). This seasonal distribution is very similar to that reported in the 1991 harvesting survey and the 1996 loggers survey (Puettmann et al. 1998a). Winter conditions provide greater access (i.e., access to areas that are inaccessible in summer), and frozen soils prevent compaction and rutting. Other reasons for winter harvests are that trees cut during winter sucker or sprout more vigorously than those felled in the summer. Thus, season of harvest can also favor one species over another in regeneration.

Slash disposal treatments can greatly influence the nutrient status of the site. Consequently, additional information about slash treatment after harvest was collected in 1996. Based on a subset of 23 respondents, most trees were delimbed in the stand, and the slash was left on the site (62,801 ac or 79% of the area harvested; see bottom of Table 3). Piling or windrowing, which concentrates the slash and thus the nutrients, was applied on 10% of the area (see Table 3). Whole tree skidding (i.e., delimbing at the landing), was conducted on 11% of the area harvested.

Eighteen respondents provided information about their sources for obtaining soil productivity information. Federal managers utilize their Ecological Classification System, while county foresters relied mainly on soil maps or biophysical inventory data. State land managers utilize all these sources, likely reflecting the different databases for different portions of the state land.

Trends and Implications

During the 1990s, prices for forest products, especially pulpwood, increased. At the same time public concerns about the ecological consequences of harvesting deepened. The forestry sector in Minnesota has reacted to both these factors. The survey indicated a trend in forest management toward an intensively managed, but more diverse forest. This trend is expressed as a shift toward leaving more residuals after harvest and increased emphasis on thinning, natural regeneration, and site preparation.

The increased attention to wildlife habitat quality, riparian protection, aesthetics, and nutrient retention is reflected in the change of silvicultural systems used in Minnesota. While clearcutting was still listed as the dominant silvicultural system used, a higher proportion of clearcuts had residual trees, snags and/or logs left after harvest. The areas clearcut with residuals can take on a variety of forms and are sometimes hard to distinguish from partial cuts. The continuation of this practice will depend on the forest types harvested (e.g., aspen cover types are more likely to be clearcut) and the perceived benefits, but also on the cost of leaving residuals on harvested sites. Changes in demands or market value of certain species and size classes might influence the future of these practices.

While the benefit of a "legacy" in the form of residual trees is well recognized (Franklin et al. 1997), it is important to point out that residual trees may have a variety of negative impacts. Direct impacts include shading and competition for water and nutrients resulting in slower growth of the regeneration (Puettmann et al. 1998b). The influence of the residuals varies by forest cover type (Smidt and Puettmann 1998). For example, leaving a residual overstory has less impact or even favors shade-tolerant species, like sugar maple or balsam fir (Roberts 1992). Light-demanding species, like quaking aspen, paper and yellow birch, and jack and red pine, might germinate or sprout. However, their growth, quality, vigor, and survival will be lower under residuals than in more open conditions (Zehngraff 1947, Stoeckeler and Macon 1956, Hove and Blinn 1990). Another concern is that leaving certain species as live residuals (e.g., red maple after quaking aspen harvest) may discriminate against regeneration of that species. These residuals will not sprout and may not be vigorous enough to produce seeds. In addition, regeneration costs may increase as mechanized operations, from skidding to herbicide applications, have to be modified to accommodate the residuals.

All organizations recognized the importance of density management to ensure a healthy, vigorous forest, and the increases in stumpage values have made thinning more feasible. Overall thinning activities have increased. Commercial thinning activities became more common on public land, while precommercial activities increased on industrial ownerships. This difference might be due to the forest cover type and stand age class distribution on the different ownerships.

The trend to rely more on natural regeneration continues in Minnesota. While aspen cover types have typically been regenerated naturally, natural regeneration efforts in other species, white pine, for example, have increased. Also, the range of acceptable species and species mixtures has expanded, thus providing more opportunity for natural regeneration. Declining budgets may also be responsible for this trend, as natural regeneration is generally cheaper (Clements and Needham 1991). On the other hand, natural regeneration from seed requires that harvesting operations are timed to coincide with good seed years. Delays in regeneration can effectively lengthen the period to achieve full stand establishment. Also, natural regeneration will likely require thinning or interplanting to achieve the desired stocking or spacing levels that match the productivity obtained by planting (Brand 1991).

Site preparation and release operations go hand-in-hand to provide good growing conditions for tree regeneration (Wagner and Zasada 1991). In the last few years, the emphasis has shifted to more intensive site preparation and less reliance on release treatments. Since crop trees are not yet present, site preparation allows for more efficient use of machinery and chemicals. Also, the choice of herbicide and timing of application does not have to be compromised to avoid injury to seedlings (Walstad and Kuch 1987). Chemical site preparation was used more frequently, except on federal and Native American ownerships. For many sites, chemical site preparation is cheaper than most alternatives. It also may be more effective and longer lasting because of the ability of herbicides to prevent perennials from sprouting. An alternative explanation for the reduction of release operations is that many organizations accept mixed species stands, and species once considered weeds and treated, are now left to grow.

In summary, the survey results partially reflect differences between the landowners in forestland (site class, forest cover type, and age class distribution) and management philosophy. For example, forest industry, while owning 11% of the land represented in the survey, is responsible for 90% of the precommercial thinning, 59% of pruning activity, and 36% of the site preparation (by acreage). This indicates that forest industry has intensified forest management practices to improve productivity. On the other hand, the trend on public land is away from intensive practices (e.g., site preparation, planting, etc.). Thus, interspersed ownerships, common in Minnesota, will be influenced by the mixture of management activities, which may lead to diverse forest conditions. However, while the practices and trends described above are a major factor influencing forest development in Minnesota, it is important to understand that forest management activities are not driven only by ownership objectives. Instead, forest management acts in conjunction with natural disturbances and successional patterns. Unexpected disturbances, like fires or windstorm, will be reflected in silvicultural practices, and any assessment of the influence of management on future forest conditions must take the interaction of these factors into account (Tester et al. 1997).

Literature Cited

Brand, D.G. 1991. Forest regeneration options in boreal forests. P. 245–254 *in* Proc. of the conf. on natural regeneration management, Simpson, C.M. (ed.). Forestry Canada, Maritimes Region.

Clark, J.S. 1990. Fire and climate change during the last 750 years in northwestern Minnesota. Ecol. Monogr. 60:136–169.

Clements, S., and T. Needham. 1991. Identification and economic evaluation of stand establishment strategies. P. 225-236 *in* Proc. of the conf. on natural regeneration management, Simpson, C.M. (ed.). Forestry Canada, Maritimes Region.

Fajvan, M A., S T Grushecky, and C C. Hassler 1998. The effects of harvesting practices on West Virginia's wood supply. J. For 96(5):33–39.

Franklin, J.F., D.R. Berg, D.A. Thornburgh, and J.C. Tappeiner III 1997. Alternative silvicultural approaches to timber harvesting Variable retention harvesting systems. P. 111–140 *in* Creating a forestry for the 21st century: The science of ecosystem management, Kohm, K.A., and J.F. Franklin (eds.). Island Press, Washington, DC

Frothingham, E.H. 1914. White pine under forest management. USDA Bull 13. USDA, Washington, DC.

Heinselman, M. 1996. The Boundary Waters wilderness ecosystem. University of Minnesota Press, Minneapolis.

Hove, G.P., and C.R. Blinn. 1990. Aspen development in Beltrami County, Minnesota. P. 113–121 *in* Proc. of the 1989 Aspen symp, Adams, R D (ed.). USDA For. Serv.Gen. Tech. Rep. NC-140.

Jaakko Pöyry Consulting, Inc. 1992a. Silvicultural systems. A background paper for a Generic Environmental Impact Statement on timber harvesting and forest management in Minnesota. Prepared for the Minnesota Environmental Quality Board. Jaakko Pöyry Consulting, Inc., Tarrytown, New York. http://www.iic.state.mn.us/download/geis/documnts.html.

Jaakko Pöyry Consulting, Inc. 1992b. Harvesting systems. A background paper for a Generic Environmental Impact Statement on timber harvesting and forest management in Minnesota. Prepared for the Minnesota Environmental Quality Board. Jaakko Pöyry Consulting, Inc., Tarrytown, New York. http://www.iic.state.mn.us/download/geis/documnts.html.

Jaakko Pöyry Consulting, Inc. 1994. Final generic environmental impact statement study on timber harvesting and forest management in Minnesota. Prepared for the Minnesota Environmental Quality Board. Jaakko Pöyry Consulting, Inc., Tarrytown, New York. http //www.iic.state.mn.us/download/geis/documnts.html.

Larson, A.M. 1972. History of the white pine industry in Minnesota. Arno Press, New York.

Leatherberry, E.C., J.C. Spencer, Jr., T.L. Schmidt, and M.R. Carrol 1995. An analysis of Minnesota's fifth forest resources inventory. USDA For. Serv. North Central For. Exp. Sta. Res. Bull. NC-165.

Puettmann, K.J., C. Blinn, H. Whittney-McIver, and A. Ek. 1998a. Status of Minnesota timber harvesting and silvicultural practices in 1996. A report to the Minnesota Forest Resources Council. Minnesota For. Resour Counc. Rep. # MP0698, St. Paul, MN. 21 p. plus append.

Puettmann, K.J., M. Smidt, and M. Duvall. 1998b. Soil characteristics influence the relationship between above- and below ground competition in *Pinus strobus* underplantings. P. 206, Symp. Abstr., Ecol. Soc. of America. 83rd Annu. Meet., Baltimore, MD.

Roberts, M.R. 1992. Stand development and overstory-understory interactions in an aspen-northern hardwoods stand. For. Ecol. Manage. 54:157–174.

Smidt, M., and K.J. Puettmann. 1998. Understory and canopy competition affect underplanted eastern white pine. For. Ecol. Manage 105(1-3):137–150

Society of American Foresters. 1994. Silviculture terminology with appendix of draft ecosystem management terms. Prepared by the Silviculture-Working Group (D2). Soc. Am. For., Bethesda, MD.

Stearns, F.W. 1997. History of the Lake States forests: Natural and human impacts. P. 8–29 *in* Lake States regional forest resources assessment: Technical papers, Vasievich, J.M., and H.H. Webster (eds.). USDA For. Serv. Gen. Tech. Rep. NC-189.

Stoeckeler, J.H., and J.W. Macon. 1956. Regeneration of aspen cutover areas in northern Wisconsin. J. For. 56:13–16.

Tester, J.R., A.M. Starfield, and L.E. Frelich. 1997. Modeling for ecosystem management in Minnesota pine forests. Biol. Cons. 80(3):313–324

Wagner, R.G., and J.C. Zasada. 1991. Integrating plant autecology and silvicultural activities to prevent forest vegetation management problems. For. Chron. 67:506–513.

Walstad, J.D. and P.J. Kuch (eds.). 1987. Forest vegetation management for conifer production. Wiley, New York.

Woolsey, T.S., Jr. and H.H. Chapman. 1914. Norway pine in the Lake States USDA Bull. 139. USDA, Washington, DC.

Zehngraff, P.J. 1947. Response of young aspen suckers to overhead shade USDA For. Serv. North Central For. Exp. Sta. Tech. Note No. 278.