Logging Options to Minimize Soil Disturbance in the Northern Lake States

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ABSTRACT: *Forest harvesting is likely to have greater impacts on site productivity than any other activity during the rotation. We determined effects of commercial, winter-logging of four aspen-dominated stands on site disturbance and development of regeneration on clay soils in western Upper Michigan. A large skidder caused deep rutting on 20% of a site in a thinning that removed 7.8 m^2 ha^{-1} (34 ft^2 ac^{-1}) of basal area, and on 38% of a clearcut site. After the first growing season, 45% of the clearcut had no aspen regeneration, and 82% had less than the recommended minimum of 15,000 (15 k) suckers ha^{-1} (6 k ac^{-1}). Options that can be utilized to minimize logging impacts include: (1) excluding riparian areas and poorly drained inclusions from cutting units; (2) dry season harvesting; (3) plowing snow from (or packing the snow on) skid trails and landings, permitting them to freeze; (4) felling with delayed skidding until trails and landings have frozen; and (5) application of best management practices (BMP) recommendations such as progressive (back-to-front) harvesting. Each of these should have minimal effects on logging costs and may be economically advantageous. As an interim guide, a minimum of 7.5 cm (3.0 in.) of soil frost is recommended for small equipment and 15 cm (6.0 in.) for large equipment. BMP guides could be effective in communicating management objectives to foresters, sale administrators, contractors, and operators, increasing their awareness of (and sensitivity toward) soil disturbance and thus, contribute to sustaining future productivity. North. J. Appl. For. 19(3):115–121.*

Key Words: Sustainable management, harvest planning, soil frost, delayed skidding.

It has been 25 yr since Perala (1977) summarized the recommendations for aspen (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) management in the Lake States, long before conserving biological diversity, ecosystem management, forest fragmentation, and riparian area management became significant management concerns. Recommendations developed 30 to 40 yr ago generally do not address these current issues. Thus, in the Great Lakes region, aspen management has been viewed rather simplistically—clearcut a mature stand, let suckers regenerate the site, wait, and then clearcut again when the stand matures—no site preparation, no cleaning, no thinning, no pest control, little thinking (Cleland et al. 2001). They also pointed out the need for alternatives to traditional aspen management recommendations to meet the objectives of modern forest management.

Likewise, there has been little change in the basic procedures of harvesting aspen—clearcut and skid the same day or shortly thereafter. The greatest changes in logging equipment during this period have been the widespread use of feller-bunchers, a decrease in the proportion of cable skidders, an increase in the number of grapple skidders, their size, horsepower, weight, static ground pressure, and potential to degrade soil properties with improper use. The capital investment required to purchase and operate large equipment frequently results in far greater emphasis on maintaining machine productivity than sustaining soil productivity.

Forest harvesting is likely to have greater impacts on soil properties, stand composition, and future site productivity than any other activity during the rotation. As part of an international network of cooperative studies on long-term soil productivity (LTSP) (Powers et al. 1990, Tiarks et al. 1993), we are evaluating effects of soil compaction and organic matter removal in the aspen forest type on four sites across the northern Lake States region and in northeastern British Columbia (Kabzems 1996, Stone and Elioff 1998,

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Stone et al. 1999, Stone 2001). To extend these experimental results to operational conditions, we are monitoring effects of commercial logging of aspen-dominated stands on soil disturbance and on development of regeneration following harvest.

In brief, we found that winter harvest using large felling and skidding equipment caused severe soil disturbance (primarily rutting) on 38% of a well drained site. After the first growing season, 45% of the area had no aspen suckers, and 82% had less than the recommended minimum of 15 k ha^{-1} (6 k ac^{-1}). Mean height of dominant suckers was 45 cm (18 in.), less than half that on two nearby sites harvested by either hand felling and a small skidder or cut-to-length (CTL) equipment (Stone and Elioff 2000). This article addresses the question: "What can we, as managers, do to prevent this kind of damage in the future?" The objectives are to: (1) summarize findings from four stands in western Upper Michigan; (2) discuss some commonly used alternative logging practices to minimize soil disturbance and impacts on the subsequent regeneration; (3) review some current research on winter logging practices, soil properties, and aspen regeneration in the northern Lake States and Canada; and (4) list some Best Management Practices (BMP) guidelines and recommendations applicable to these, and similar sites.

Methods

Stand and Soil Conditions

We selected four stands from conventional timber sales on the Ontonagon Ranger District, Ottawa National Forest. The overstory of each was dominated by aspen but included a codominant component, or a subcanopy of either northern hardwood species or white spruce (*Picea glauca* [Moench] Voss) and balsam fir (*Abies balsamea* [L.] Mill.) (Table 1). More detailed stand conditions and soil and site characteristics were reported earlier (Stone 1997, Stone and Elioff 2000). In brief, each site is dominated by calcareous clay soils, and each stand was commercially harvested during midwinter by different loggers using different combinations of felling and skidding equipment. The area receives frequent snowfall, typically beginning in early November, so the soils rarely, if ever, freeze.

Prior to harvest, we established transects about 30 m (1.5 chains) apart across each site and marked sample points every 5 m (0.25 chain) to assess soil disturbance and to monitor development of regeneration. Every 25 m along each line, we measured the basal area of all live trees ≥ 10 cm (4 in.) dbh using a 10-factor prisim, recorded the basal area by species and the predominant overstory species. Mean basal area of aspen, associated commercial species, and total basal area were summarized for each stand (Table 1).

Harvesting

The Marsh Grass site was commercially clearcut during late December 1995 and early January 1996 with a Hydro-Ax model 311 feller-buncher and a Caterpillar 518 grapple skidder. Snow depths ranged from 90 to 100 cm (36 to 40 in.), and the soils were not frozen. The trees were limbed and topped on site and skidded tree-length to a landing beside an existing road. Scattered immature balsam-fir <10 cm (4.0 in.) dbh remained on the site. The operator then moved to the nearby North Country site, felled and limbed the aspen and associated hardwoods to clear a temporary (winter) road and landing, and began thinning the mature aspen from the rest of the stand. However, the equipment produced deep rutting and damage to the residual stand, so harvest operations were suspended on February 7. A second attempt was made during late May and early June 1998, but the soils were still too wet to support the equipment, and logging was again suspended. The job was completed during January and February 1999 after plowing the snow from the skid trails, permitting them to freeze sufficiently to support the large equipment.

The silvicultural prescription for the West Branch stand was clearcut with reserves to retain scattered, pole-size white pine (*Pinus strobus* L.) and an occasional northern red oak (*Quercus rubra* L.). The site was harvested during January and February 1996 by chainsaw felling and limbing and tree-length skidding with a John Deere 440 cable skidder to a temporary road constructed through the central portion of the stand. A John Deere 550 crawler tractor was used to plow snow from the skid trails permitting them to freeze. Snow depths and soil conditions were similar to those on the nearby Marsh Grass site that was harvested at the same time.

Table 1. Preharvest basal area (≥10 cm dbh) of aspen and associated species on the study sites.

Site	Species	Basal area (m^2 ha^{-1})	Basal area (ft^2 ac^{-1})	Basal area (%)
Marsh Grass	Aspen	10.3	45	46
	Northern hardwoods*	12.2	53	54
	Total	22.5	98	
North Country	Aspen	7.8	34	31
	Northern hardwoods*	17.7	77	69
	Total	25.5	111	
West Branch	Aspen/paper birch	13.8	60	52
	Sugar maple/white spruce †	12.9	56	48
	Total	26.6	116	
Beaver Pond	Aspen	13.8	60	65
	White spruce/balsam fir ††	7.3	32	35
	Total	21.1	92	

* Predominantly black ash (*Fraxinus americana* Marsh.) and basswood (*Tilia americana* L.); sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), yellow birch (*Betula alleghaniensis* Britt.), northern red oak (*Quercus rubra* L.), and balsam fir also were present.
† Sugar and red maple, white spruce, red oak, white pine (*Pinus strobus* L.), and balsam fir.
†† Sugar and red maple, basswood, black ash, paper birch, and northern white-cedar (*Thuja occidentalis* L.).

The silvicultural prescription for the Beaver Pond stand was clearcut with reserves to retain occasional, immature (< 10 cm, 4.0 in.) northern white-cedar (*Thuja occidentalis* L.), white spruce, and balsam fir. The site was harvested during January and February 1997 with a six-wheel drive Timberjack 1270B CTL harvester and a six-wheel drive Timberjack 1010B forwarder. Snow depths ranged from 76 to 90 cm (30 to 36 in.), and the soils were not frozen. After logging was completed on each of the three clearcuts, all residual hardwood stems >5 cm (2.0 in.) were cut with chainsaws, a standard practice on this District.

Soil Disturbance and Regeneration

During the first spring following logging we visually classified soil disturbance on a circular, 5 m^2 plot at each sample point of each transect on the Marsh Grass and West Branch sites (1996), on the Beaver Pond site (1997), and on various portions of the North Country site between 1996 and 2000 using the following classes: (1) litter layer intact; (2) litter removed; (3) litter-soil mixed; (4) surface soil moved; (5) machine track or rut <10 cm deep; (6) rut 10 cm to 20 cm; (7) rut >20 cm; (8) road, trail, or landing; (9) slash >1.0 m deep or logs >50 cm deep; or (10) nonsoil (stumps, rock, etc.). Most plots included more than one class of disturbance, so we visually divided each plot into ten wedge-shaped segments and recorded the number of segments in each class. For each disturbance class, the mean of the segments for all plots provided the percent over the entire site. The percentage data were then grouped into four general classes: none (1); light (2 to 4); heavy (5 to 8); or nonsoil (slash and stumps). In September, after the first growing season, the number of aspen suckers on each 5 m^2 plot and the height of the dominant sucker were recorded on each of the three clearcut sites. Regeneration data on the North Country site were collected during September 2000, 2 yr after the majority of the stand was harvested. The percent of plots stocked, mean sucker density, and height of the dominant sucker were calculated for each site (Table 2).

Results

Soil Disturbance

The large equipment and lack of operator skill and/or sensitivity to soil disturbance produced heavy disturbance, primarily rutting, on 38% of the Marsh Grass site (Table 2). Likewise, removing 31% of the basal area from the North Country site by the same operator resulted in deep rutting on 20% of the area. Chainsaw felling and the small skidder produced heavy disturbance on 12% of the West Branch site, primarily due to the temporary road, with minor rutting throughout most of the site. The CTL equipment produced heavy disturbance on 11% of the Beaver Pond site, primarily from forwarder traffic, because the operator did not always travel on the slash mat left by the harvester. More detailed results were presented earlier (Stone and Elioff 2000).

Regeneration

The greatest aspen stocking, sucker density, and first-year growth occurred on the least disturbed West Branch and Beaver Pond sites (Table 2). Likewise, the lowest stocking, density, and growth were recorded on the most heavily disturbed Marsh Grass site. Results for the partially cut North Country stand were intermediate between those of the clearcuts. The mean sucker height for the North Country site includes the older stems on 95 plots resulting from the first two logging attempts. Omitting them from the data gives a mean 2 yr height of 113 cm on the remaining 500 plots.

Discussion

Silviculture, Planning, and Review

As the areas of predominantly aspen growing on well-drained sites are depleted, and market demands remain strong, the continued application of simple silviculture prescriptions serves to maintain simple, unnatural ecosystems that discriminate against the more shade-tolerant species that have adapted to the sites (Mladenoff and Pastor 1993, Cleland et al. 2001). When the cutting unit boundaries include poorly drained inclusions and drainages (riparian areas) occupied by substantial amounts of black ash, red maple, basswood, and associated moist-site species (see footnotes, Table 1), it sets the stage for the problems encountered in thinning the North Country site and the amount of deep rutting on both sites where the large equipment was used. This combination of circumstances indicates that managers need to place greater emphasis on silvicultural and harvesting options to minimize soil damage during logging.

Most aspen-dominated stands growing on medium and fine textured soils include substantial amounts of spruce and balsam regeneration and/or quality pole-size northern hardwood growing stock (Table 1). These stands look far different when viewed from the ground looking up than they do from aerial photos. Sound silviculture prescriptions require on-site stand examination and evaluation of

Table 2. Percent of heavy disturbance, area stocked, mean sucker density, and mean height of dominant suckers on four sites harvested with different equipment.

Site	Sample plots (n)	Heavy	Stocked	Density (k ha^{-1})	Height (cm)
		(%)	(%)		
Marsh Grass*	345	38	55	9.0	45
North Country*	595	20	67	11.8	116 [§]
West Branch †	550	12	92	34.5	97
Beaver Pond ††	690	11	83	23.8	101

* Hydro-Ax feller-buncher and Cat 518 grapple skidder.
† JD 440 cable skidder and JD 550 crawler tractor snowplow.
†† Timberjack six-wheel-drive CTL processor and forwarder
§ Primarily 2 yr growth.

the data with clearly defined objectives for future stand conditions. With well planned logging, most of this advance softwood regeneration can be retained (Navratil et al. 1994). Rather than liquidating the pole-size northern hardwoods at pulpwood or firewood prices, the silviculture prescritions should be planned to maintain species diversity, reduce forest fragmentation, and produce high-value products (Niese and Strong 1992, Niese et al. 1995, Strong et al. 1995). Retaining the softwood advance regeneration and the northern hardwood growing stock would provide both soil management and silvicultural advantages (Stone and Elioff 2000). Assuming that machine traffic is roughly proportional to the volume removed, removing only the aspen and mature conifers and hardwoods would require less machine traffic, and consequently, result in less site disturbance. The remaining partial canopy and advance regeneration would maintain a portion of the normal evapotranspiration and nutrient cycling processes, thus reducing the risk of invasion by sedges, alder (*Alnus rugosa* (Du Roi) Spreng.), and willow (*Salix* spp.).

Grigal (2000) reemphasized the need for thorough planning of harvest operations due to our inability to control weather and site factors such as slope characteristics, rainfall intensity, or soil texture. He emphasized that extreme care must be taken to minimize alteration of soil properties. Even in areas where the soils normally freeze each winter, experimentally compacted soils have shown no change in bulk density or soil strength 5 yr after treatment (Stone and Elioff 1998). In fact, the effects of severe compaction and/or rutting are likely to persist for decades (Corns 1988, Grigal 2000), a century (Sharratt et al. 1998), or possibly longer (Curran 1999). Some forest management impacts are unavoidable either because of physical factors or economic considerations. Sound forest management practices, including minimizing the area affected (Grigal 2000) and the careful application of Best Management Practices (BMPs), can effectively mitigate many of the undesirable consequences of land management activities. Cutting unit boundaries need to exclude the riparian areas occupied by black ash, red maple, and associated moist-site species. Likewise, poorly drained inclusions should be delineated on the ground during sale preparation and marked with a different color than the stand boundary. Marking the trees on two sides makes them much more visible and easier for the equipment operators to follow (Dave Franzen, pers. comm., Watersmeet, MI).

Some of the most favorable operating conditions, profitable logging jobs, and highest stumpage returns are on management areas that utilize well-planned, designated skid trails and interdisciplinary review of silviculture prescriptions that include the timber sale administrator (Rick Dehaan, pers. comm., Mass City, MI and Dave Franzen, pers. comm., Watersmeet, MI). Some corporate managers also include the logger in the field review. It is important to meet with operators on-site before harvesting to make sure provisions of the harvest plan are well understood (Mattson et al. 2000). Active supervision during harvest operations is critical to ensure that the plan is being implemented properly.

Dry Season Harvesting

An obvious alternative is harvesting when the soils are sufficiently dry and have the bearing strength to minimize soil compaction and rutting. In addition, late summer skidding can be highly effective in reducing competition from shade tolerant shrubs such as beaked hazel (*Corylus cornuta* Marsh.) and mountain maple (*Acer spicatum* Lam.) (Navratil 1991). Despite these advantages, many managers believe that winter logging is required for "adequate" aspen regeneration; this is not always true (Bates et al. 1989). For example, in a reserve tree study in six stands on the Superior National Forest where 17 to 37 mature aspen ha^{-1} (7 to 15 ac^{-1}) were retained, greater sucker density (>33 k ac^{-1}) occurred on a site harvested in July than on four nearby sites harvested during the winter (Stone et al. 2001). Graham et al. (1963) considered a mean sucker density of 15 k ha^{-1} (6 k ac^{-1}) as minimum and 30 k ha^{-1} (12 k ac^{-1}) as optimal. This raises the question of whether winter harvesting, when soil water content normally is at (or above) field capacity to produce high sucker densities, is worth the cost in terms of soil disturbance with the potential to reduce future productivity.

During the early stages of stand development, most suckers are lost due to intraspecific (primarily intraclonal) competition and the resulting self-thinning (Perala et al. 1999). This raises the additional question of whether we really need or want an initial density of >100 k suckers ha^{-1} (>43,560 ac^{-1}). In the reserve tree study, retaining 17 to 37 dominant aspen ha^{-1} (7 to 15 ac^{-1}) decreased first-year sucker density by about 40% and increased their diameter and height growth by 30% (Stone et al. 2001). In general, winter logging produces higher sucker densities than summer harvesting (Bates et al. 1989, Peterson and Peterson 1992). Managers need to evaluate the trade-offs between the prospects of high sucker density, intense competition, the resulting lower early growth, and the risk of reduced future productivity due to soil damage *vs.* probable lower sucker density, greater early growth, and less risk of long-term site degradation.

Snow Removal

Snow cover provides insulation and can prevent soil freezing (Verry 1991). Plowing the snow from skid trails and landings normally will permit the soils to freeze, and thereby alleviate compaction and rutting. Soil frost can make vehicle and equipment operations possible on ground that is otherwise nontrafficable (Shoop 1995). The depth of frost required to support equipment depends on the static ground pressure of the machine and the forces exerted while it is under load. LeDoux (1998) summarized the static ground pressure representing several classes of typical logging equipment (Table 3).

Table 3. Static ground pressure estimates for selected harvesting equipment.[a]

	Static ground pressure	
Equipment type	(k Pa)	(PSI)
Flexible tracked skidders	20–40	3–6
Rigid tracked crawlers	40–70	6–10
Forwarder with 3 to 4 axles	55–70	8–10
Rubber-tired skidders	80–110	12–16
Forwarder with 2 axles	100–125	14–18

[a] LeDoux 1998.

However, soil loading is a dynamic process that cannot be inferred from averaging the weight of the machine (McNabb 1999) because the combined forces of compression, shear, slippage, and vibration increase the effective load well beyond static loads. Under load, machines typically apply 1.5 to 2.0 times the static load and for brief periods may reach 3.0 to 4.0 times that value (Wulfsohn 1999). Moreover, the level (severity) of any site impact is directly related to the type of equipment, the way in which it is used (or misused), and the site conditions at the time of use (Greenway 1999). He suggests that there are no "high impact" pieces of equipment, rather that the range of site conditions over which a piece of equipment will have minimal impact on aspen regeneration will differ for each piece of equipment and site condition.

In the northern Lake States, some loggers routinely plow the snow from skid trails to prevent "wear and tear" on their equipment and reduce fuel costs. They believe that the time and cost of plowing the trails is recovered by the skidder operators not having to contend with deep snow and mud and by the fuel savings realized by having a smooth, solid surface to operate on. While we have no data to either support or refute this contention, they probably are correct. Difficult operating conditions result in decreased harvest system productivity and lower profitability (Mattson et al. 2000). Also, machines subjected to severe operating conditions require more maintenance and repair than similar machines operating under favorable conditions, further reducing profits. Considering equipment maintenance and fuel costs, the time and cost of plowing the trails may be economically advantageous.

This strategy also is being evaluated in British Columbia: blade (plow) the snow from skid trails and let the soil freeze before operating (Curran 1999). In harvesting trials, they found no soil deformation (visible tracks) with 7.5 cm (3.0 in.) of frost in the mineral soil. The Hiawatha National Forest specifies 15 cm (6.0 in.) of frozen soil or 30 cm (12 in.) of packed snow for winter access roads, skid trails, and landings (USDA Forest Service 1986). Frozen skid trails, as used on the West Branch site, should be encouraged as a standard practice, rather than considered only as a last resort, as in the third attempt to complete harvesting of the North Country site.

Soil Frost

Available data on the bearing strength of frozen soils are very limited (Shoop 1995) and an adaptive management approach is required to balance market demands for wood products and our responsibilities to maintain hydrologic functions, ecosystem processes, and soil productivity. As an interim guide, a minimum of 7.5 cm (3.0 in.) of frozen *mineral* soil appears sufficient for operators with small equipment (see footnotes, Table 2), whereas 15 cm (6.0 in.) is more appropriate for those with large equipment (Table 3). Depth of frost can be determined with a frost probe constructed from 12.7 mm (1/2 in.) steel rod with one end sharpened to a 30° cone, pounding it into the soil until it breaks through the frozen zone, and recording the depth. A minimum of 30 points distributed across the planned travel area should provide a reliable sample.

Delayed Skidding

In Alberta, Greenway (1999) evaluated different methods of aiding frost development and their effects on soil bulk density, aeration porosity, and development of aspen regeneration. On one site, the block was felled and bunched, and the skidder brought two loads to the landing to pack the snow on the skid trail and landing. They then waited a minimum of 48 hr before completing skidding of the block. Air temperatures during the period were below –20° C (–4° F). On the areas behind the deck, where the snow had been packed, the surface soil had frozen solid.

A second site was harvested the following year with no significant frost in the mineral soil due to heavy snow accumulation. All trees were felled and bunched in late December, but skidding was delayed until late February. Low air temperatures during this period resulted in most areas, adjacent to roads where the snow had been compacted by the feller-buncher, being well-frozen; the remainder of the block was patchily frozen. However, areas beneath the butt end of the bunches, where the snow had been compacted had frozen very hard, while the soil beneath the tree tops where the snow was undisturbed, was not frozen. This approach undoubtedly has been inadvertently applied in the Lake States, but should be recognized as a viable alternative to same-day skidding to minimize soil compaction and rutting.

Best Management Practices (BMP)s

Minnesota, Wisconsin, and Michigan each have developed BMP guidelines and recommendations addressing various aspects of harvesting. Those that seem particularly applicable to these, and similar sites include: (1) excluding riparian areas from sale area boundaries; (2) design and layout of roads, trails, and landings to minimize the amount of the site affected by logging; (3) progressive (back-to-front) harvesting to concentrate vehicle traffic and protect advance regeneration and/or reserved growing stock (Figure 1); (4) plowing or packing the snow cover to enhance soil freezing before operation; (5) operation of equipment on slash mats; and (6) use of low ground pressure (LPG) equipment. These guides vary from state to state, but all have the common objectives of minimizing stand and site damage, and maintaining forest productivity and water quality. As an educational and extension tool, they could be effective in communicating management objectives to silviculturists, timber sale administrators, logging contractors, and equipment operators, thereby increasing their awareness of (and sensitivity toward) soil and site disturbance and thus, contribute to sustaining future productivity.

Summary and Management Implications

Forest harvesting is likely to have greater impacts on soil properties, species composition, and future productivity than any other activity during the rotation. Soil compaction and/or rutting are the most common results, and their effects are likely to persist for decades, and possibly longer. Managers need to take positive steps to minimize both the magnitude of impacts and the proportion of the area affected. Sustaining productivity begins with a sound

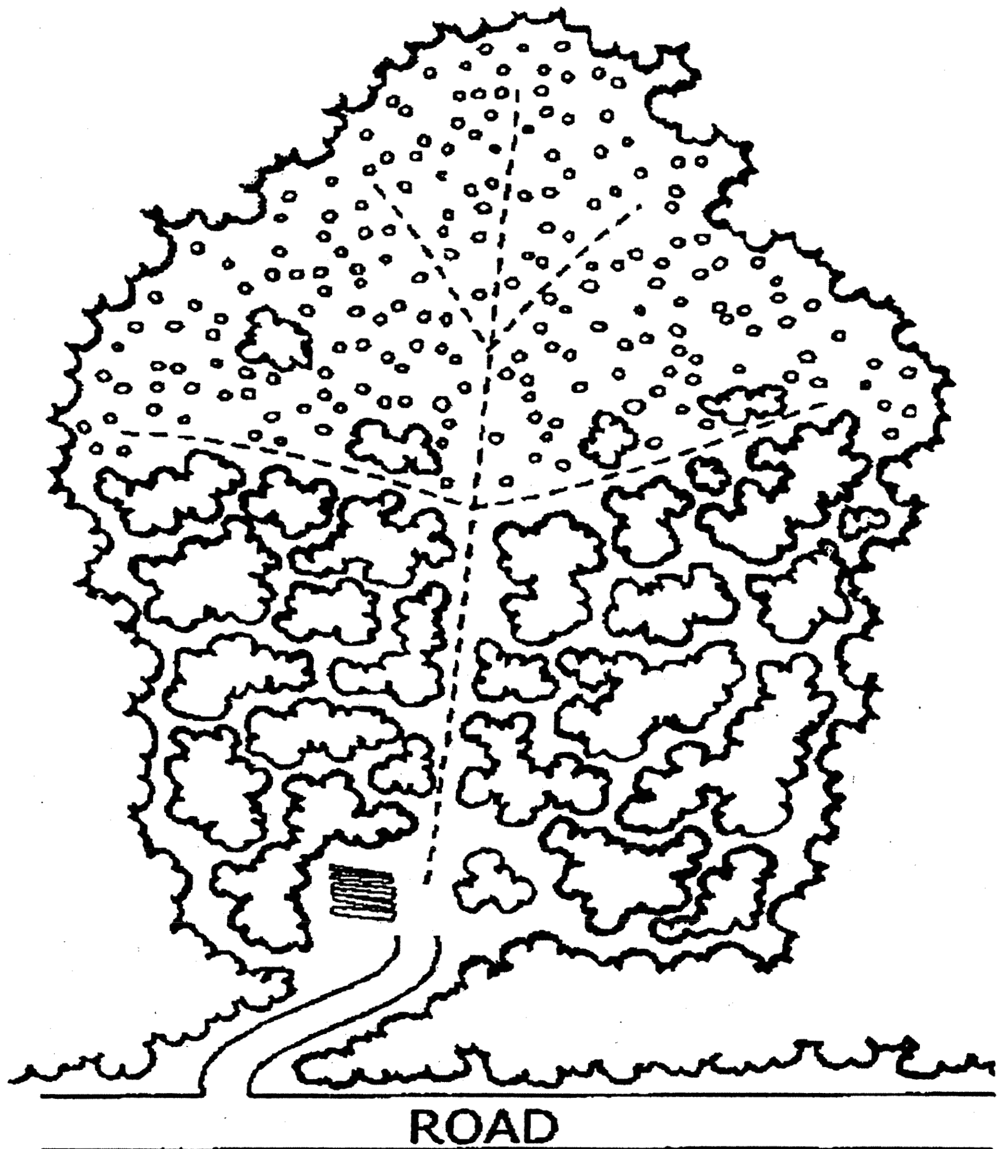

Figure 1. Example of a progressive (back-to-front) harvest pattern to concentrate machine traffic and protect advance regeneration and/or reserved growing stock. (Figure courtesy of Minnesota Forest Resources Council, 1999).

silviculture prescription based on current stand and site conditions, indicators of potential productivity, and clearly defined objectives. Simple silviculture prescriptions maintain simple, unnatural ecosystems. Traditional aspen management practices are not likely to meet the objectives of modern forest management. Cutting unit boundaries need to exclude the riparian areas occupied by ash and associated moist-site species. Likewise, poorly drained inclusions should be delineated on the ground during sale preparation and marked with a different color than the stand boundary. Active supervision during harvesting is critical.

The size, weight, and power of logging equipment have increased greatly during the last 25 yr, and its misuse can produce serious site degradation in a short time. There are common-sense options that can be utilized to minimize logging impacts including: (1) dry season harvesting; (2) plowing snow from (or packing the snow on) skid trails and landings, permitting them to freeze; and (3) felling with delayed skidding until trails and landings have frozen. Each of these should have minimal effects on logging costs, and considering equipment maintenance and fuel costs, may be economically advantageous. As an interim guide, a minimum of 7.5 cm (3.0 in.) of soil frost is recommended for small equipment and 15 cm (6.0 in.) for large equipment. BMP guides could be effective in communicating management objectives to foresters, sale administrators, contractors, and operators, increasing their awareness of, and sensitivity to soil disturbance, and thus contribute to sustaining future productivity.

While these results are from aspen-dominated stands on clay soils, they also apply to large areas of northern hardwoods growing on medium and fine textured soils throughout the Lake States region. These soils frequently are underlain by a fragipan, resulting in perched water whenever soil water recharge exceeds evapotranspiration (most of the dormant season). The saturated horizons above the fragipan makes them particularly susceptible to rutting and root damage, potentially a greater problem in high-value, all-age northern hardwood stands than in regenerating aspen stands where remediation measures (e.g., interplanting conifer seedlings), are possible. They also apply to other forest types (e.g., spruce and balsam), growing on shallow soils where bedrock impedes internal drainage, resulting in seasonally perched water.

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