Soil disturbance and aspen regeneration on clay soils: Three case histories

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Sustaining forest productivity requires maintaining soil productivity and prompt establishment of adequate regeneration following harvest. We determined effects of commercial, winter-logging of aspen-dominated stands on soil disturbance and development of regeneration on three sites with clay soils. We established transects across each site, recorded pre-harvest stand information, post-harvest site disturbance, and first-year aspen sucker density and height. Use of large logging equipment produced heavy disturbance on 38% of a well-drained site; 45% of the area had no aspen suckers and 82% had less than the recommended minimum of 15 000 (15 k) suckers per ha (6 k ac^{-1}). Mean height of dominant suckers was 45 cm (18 in). Hand felling and a small skidder caused heavy disturbance on 12% of a moderately well-drained site. Sucker density averaged 34 k ha^{-1} (14 k ac^{-1}) and height was 97 cm (38 in). Cut-to-length (CTL) equipment produced heavy disturbance on 11% of a somewhat poorly-drained site, mean sucker density of 24 k ha^{-1} (9.6 k ac^{-1}), and height of 101 cm (40 in). These severely disturbed areas essentially are removed from the aspen-producing land base. Retaining the northern hardwood and conifer growing stock would result in less site disturbance and help maintain natural hydrologic and nutrient cycling processes.

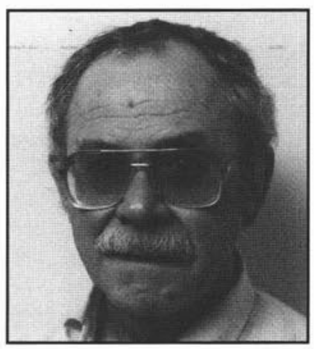
Key words: aspen management, site disturbance, sustainable management, logging damage, soil rutting, root damage, evapotranspiration, soil aeration, clearcutting with residuals

La durabilité de la productivité forestière requiert le maintien de la productivité du sol et l'établissement rapide d'une régénération adéquate après la récolte. Nous avons déterminé les effets de la récolte commerciale effectuée au cours de l'hiver de peuplements à dominance de peuplier sur la perturbation du sol et le développement de la régénération sur trois stations composées de sol argileux. Nous avons effectué des relevés sur chacune des stations, afin de noter l'information sur le peuplement avant la récolte, la perturbation de la station après la récolte, et la densité et la hauteur des drageons de peuplier après un an de croissance. L'utilisation d'une machinerie lourde d'exploitation forestière a engendré une forte perturbation de 38 % de la station à drainage rapide, 45 % de la superficie ne comptait pas de drageon et 82 % avait moins que le minimum recommandé de 15 000 (15 k) drageons par ha (6 k ac^{-1}). La hauteur moyenne des drageons dominants était de 45 cm (18 po) L'abattage manuel et l'utilisation d'un petit débardeur ont engendré une forte perturbation sur 12 % de la station à drainage relativement adéquat. La densité des drageons était en moyenne de 34 k ha^{-1} (14 k ac^{-1}) et la hauteur atteignait 97 cm (38 po). L'équipement de coupe en longueur a engendré une forte perturbation de 11 % de la station relativement mal drainée, la densité moyenne des drageons était de 24 k ha^{-1} (9,6 k ac^{-1}), et la hauteur, de 101 cm (40 po). Ces sites très perturbés sont dans l'ensemble retirés du territoire productif du peuplier. Le maintien des stocks en croissance de feuillus nordiques et de conifères permettrait de moins perturber la station et aiderait au maintien des processus naturels d'hydrologie et du cycle des éléments nutritifs.

Mots-clés: aménagement du peuplier, perturbation de la station, aménagement durable, blessures d'exploitation, orniérage, blessures aux racines, évapotranspiration, aération du sol, coupe à blanc avec arbres résiduels

Introduction

Sustaining forest productivity from one rotation to the next requires: (1) maintaining soil productivity, and (2) prompt establishment of adequate regeneration. Forest harvesting is likely to have greater impacts on site productivity than any other activity during the rotation. Harvesting procedures that degrade soil properties and damage the parent root systems can impact the development of aspen suckers and thus, the density and species composition of the subsequent regeneration. 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 (*Populus tremuloides* Michx. and *P. grandidentata* Michx.) forest type across the northern Great Lakes region and in northeastern British Columbia (Kabzems 1996, Stone and Elioff 1998, Stone *et al.* 1999). To extend these experimental results to operational conditions, we are monitoring effects of commercial logging of aspen-dominated stands on site disturbance and on the composition and development of regeneration for several years following harvest. We report results from three sites on the Ontonagon Ranger District, Ottawa National



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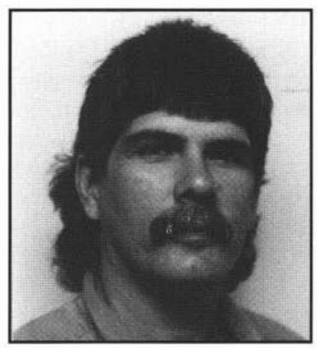

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Forest in western Upper Michigan. Each site is dominated by calcareous clay soils (Table 1) and was commercially harvested during mid-winter by different loggers using different combinations of felling and skidding equipment.

Methods

Stand and Site Conditions

District personnel provided stand information and Landtype Phase (Avers *et al.* 1994, Cleland *et al.* 1997) maps and site descriptions for several 60- to 65-year-old stands that were included

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Table 1. Characteristics of study sites on the Ontonagon Ranger District, Ottawa National Forest, western Upper Michigan

Site Name	Stand Area (ha)	Landtype Phase[a]	Parent Material	Drainage Class[b]	Habitat Type[c]	Forest Type	Est. Site Index-m (ft)
Marsh Grass	10	226B	Clay/Till[d]	Well	TAM	Aspen/NH[e]	20 (65)
West Branch	13	216B	Clay	MW	TAM	Aspen/NH	18 (60)
Beaver Pond	14	217A	Clay	SP	TTP	Aspen/BF[f]	17 (55)

[a]Also referred to as Ecological Land Type Phase (Avers *et al.* 1994).
[b]Well – well-drained; MW – moderately well-drained; SP – somewhat poorly-drained.
[c]TAM - *Tsuga-Acer-Mitchella*; TTP - *Tsuga-Thuja-Petastites*; (Coffman *et al.* 1983, Kotar *et al.* 1988).
[d]Lacustrine clay deposited over till.
[e]Predominantly black ash and basswood; sugar maple, red maple, yellow birch, and red oak also present.
[f]Aspen, balsam fir, and white spruce.

Table 2. Pre-harvest merchantable basal area of aspen and associated species on the study sites

Site	Species	Basal area		
		(m^2 ha^{-1})	(ft^2 ac^{-1})	(%)
Marsh Grass	Aspen	10.3	45	46
	Northern hardwoods	12.2	53	54
	Total	22.5	98	
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	

in conventional national forest timber sales but had not yet been harvested. The stands were typical of those throughout the northern Great Lakes region that developed following exploitative logging and extensive slash-fuelled wildfires (Stone and Strand 1997). We previously described four stands growing on soils similar to the LTSP installation and with a range of soil and site characteristics and stand conditions (Stone 1997). However, when logging of one of them (North Country) began, the equipment produced deep rutting and damage to the residual stand, so harvest operations were suspended. The remaining three sites provide a case history of conventional, winter harvesting of aspen-dominated stands on soils with a range of internal drainage (Table 1). Except for scattered minor depressions and drainages, the sites are nearly level (< 3% slope). We used data from the LTSP plots and nearby stands (Alban *et al.* 1991) to estimate the 50-year site index for aspen. The Marsh Grass site is predominantly well-drained with an estimated site index of about 20 m (65 ft). Soils on the West Branch site are most similar to those of the LTSP installation, moderately well-drained, with a site index of about 18 m (60 ft). The Beaver Pond site is predominantly somewhat poorly-drained and contains poorly-drained inclusions; site index averaged about 17 m (55 ft).

The overstorey of each stand was dominated by aspen but included a codominant component, or a subcanopy of northern hardwood species, white spruce (*Picea glauca* (Moench) Voss), and balsam fir (*Abies balsamea* (L.) Mill.) (Table 2). The Marsh Grass stand had a merchantable basal area of 22.5 m^2 ha^{-1} (98 ft^2 ac^{-1}); 46% was aspen. The balance was predominantly black ash (*Fraxinus nigra* 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. Aspen and paper birch (*Betula. papyrifera* Marsh.) were the predominant species in the West Branch stand and made up 52% of the basal area. Sugar and red maple, white spruce, red oak, white pine (*Pinus strobus* L.), and balsam fir comprised the remainder. The Beaver Pond stand was classified as over-mature aspen/balsam fir; however, much of the balsam had been wind-thrown one to three years before the study was started, leaving a predominantly aspen overstorey comprising 65% of the 21.1 m^2 ha^{-1} (92 ft^2 ac^{-1}) of total basal area. The balance included white spruce, balsam fir, sugar and red maple, basswood, black ash, paper birch, and northern white-cedar (*Thuja occidentalis* L.).

Sampling and Measurements

Prior to harvest, we established transects about 30 m (1.5 chains) apart across each stand and marked sample points every 5 m (0.25 chain) to assess site disturbance and to monitor development of regeneration (Table 3). Every 25 m along each line, we measured the basal area of all live trees ≥10 cm (4 in) dbh, recorded the basal area of aspen, total basal area of all species, and the predominant overstorey species. Mean basal area of aspen, total basal area, and predominant overstorey species were summarized for each stand.

The Marsh Grass stand was harvested during late December, 1995 and early January, 1996. Snow depths ranged from 90 to 100 cm (36 to 40 in) and the soils were not frozen. The logging equipment included a Hydro-Ax model 311 feller-buncher, a Caterpillar 518 grapple skidder, and a slasher-loader set up at a roadside landing. The trees were limbed and topped on site and skidded tree-length to the landing. The West Branch stand was harvested during the same period 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. The Beaver Pond stand was harvested during January and February, 1997 with a six-wheel drive Timberjack 1270B cut-to-length 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 site, all residual hardwood stems > 5 cm (2 in) dbh were cut with chainsaws, a standard practice on this District.

During the first spring following logging we visually classified soil disturbance on a circular, 5-m^2 plot at each sample point on each site using the following classes: (1) litter layer intact; (2) litter removed; (3) litter-soil mixed; (4) surface soil moved; (5) machine track; (6) rut <10 cm deep; (7) rut 10 cm

Table 3. Distribution of general disturbance classes on three sites harvested with different equipment

Site	Sample Plots (n)	None	Light	Heavy	Slash
		Percent of sample area			
Marsh Grass[a]	345	43	13	38	6
West Branch[b]	550	67	5	12	16
Beaver Pond[c]	690	49	22	11	18

[a]Hydro-Ax feller-buncher and Cat 518 grapple skidder.
[b]JD 440 cable skidder and JD 550 crawler tractor snowplow.
[c]Timberjack six-wheel-drive CTL processor and forwarder.

Table 4. Percent of sample area in first-year aspen density classes on sites harvested with different equipment

Sucker density				
(k ha^{-1})	(k ac^{-1})	Marsh Grass[a]	West Branch	Beaver Pond
None	None	44.9	8.2	17.4
0.1 – 14.9	0.1 – 5.9	37.4	23.3	26.8
15.0 – 29.9	6.0 – 11.9	7.6	23.2	22.6
30.0 – 44.9	12.0 – 17.9	4.1	19.9	16.4
45.0 – 59.9	18.0 – 23.9	2.9	10.0	9.4
60.0 – 74.9	24.0 – 29.9	2.0	5.6	4.4
75.0 – 89.9	30.0 – 35.9	0.3	3.5	1.4
90.0 +	36.0 +	0.6	6.5	1.6

[a]See footnotes, Table 3.

to 20 cm; (8) rut >20 cm; (9) road, trail, or landing; (10) slash > 1 m deep or logs ≥ 50 cm deep; or (11) non-soil (predominantly stumps). When a plot included more than one class of disturbance, we estimated the area occupied by each class to the nearest 10 percent. The disturbance data were then consolidated into four general classes: "none" (1); "light" (2 to 5); "heavy" (6 to 9); or "non-soil" (slash and stumps). This grouping scheme was based on previous observations of soil disturbance and aspen regeneration on numerous additional recently harvested sites. We estimated the area of the site in each disturbance class based on the plot totals and calculated a weighted disturbance index for each plot by assigning a numeric value of 1, 2, or 3 to each general disturbance class and multiplying by the proportion of the area occupied by each. For example, if 60% of a plot was classified as "none," 30% as "light," and 10% "heavy," the weighted index was (1×6) + (2×3) + (3×1) = 15. Thus, if all 10 segments of a plot were classified as "none," the disturbance index was 10, or if all 10 were classified as "heavy," the index was 30.

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. The percentage of plots stocked and mean density of suckers were calculated for each stand. Relations between dominant sucker height and the weighted disturbance index were evaluated by linear regression (Analytical Software 1998).

Results

The combination of equipment size and operator skill and/or sensitivity to soil disturbance resulted in large differences in amount of area impacted by logging. The large equipment used on the Marsh Grass site produced visible soil disturbance on 51% of the sample area, of which 38% was heavy disturbance (Table 3). Chainsaw felling and the small skidder resulted in visible disturbance on 17% of the West Branch site, the least of the three logging jobs. The cut-to-length equipment produced visible soil disturbance on 33% of the Beaver Pond site with 11% heavily disturbed, the least heavy disturbance of the three operations.

Winter harvesting of these aspen-dominated stands resulted in large differences in first-year regeneration of aspen suckers among the three sites. Most striking was the difference in the number of plots with no suckers, nearly 45% on the heavily disturbed Marsh Grass site compared to 8% and 17% on the less disturbed West Branch and Beaver Pond sites (Table 4). Likewise, more than 37% of the Marsh Grass site had less than 15 000 suckers per ha (6 k ac^{-1}) compared to about 25% on the other two sites. Mean density of aspen on the Marsh Grass site was 9 000 suckers per ha (3.6 k ac^{-1}), approximately one-fourth to one-third that on the other two sites (Table 5). Moreover, mean height of the suckers was less than half that of the other two sites. The linear regression between sucker height and the weighted disturbance index was highly significant, (p <0.001, r^2 = 0.10) for the Marsh Grass site (Fig. 1) but not for the other two.

Discussion

Site Disturbance

Both the area affected and degree of site disturbance during harvesting can vary greatly depending on soil conditions, type and size of equipment, and operator practices. In Lake States clearcuts, estimates of 50 to 95% of the area disturbed are common (Grigal and Bates 1992). Our estimates of the area that was disturbed probably are conservative for two reasons. First, machine traffic in deep snow can compact soil without leaving tracks (unpublished data on file), and secondly, ground vegetation and logging slash can conceal disturbance that is present. This underestimate is greatest on the Marsh Grass site where the feller-buncher had to approach every tree that was cut. The data are more representative of actual conditions on the other two sites. On the Beaver Pond site, the boom of the harvester reached 5–6 m (16–20 ft) each side of the traffic corridor and the operator used the "walk-on-slash" technique. On the West

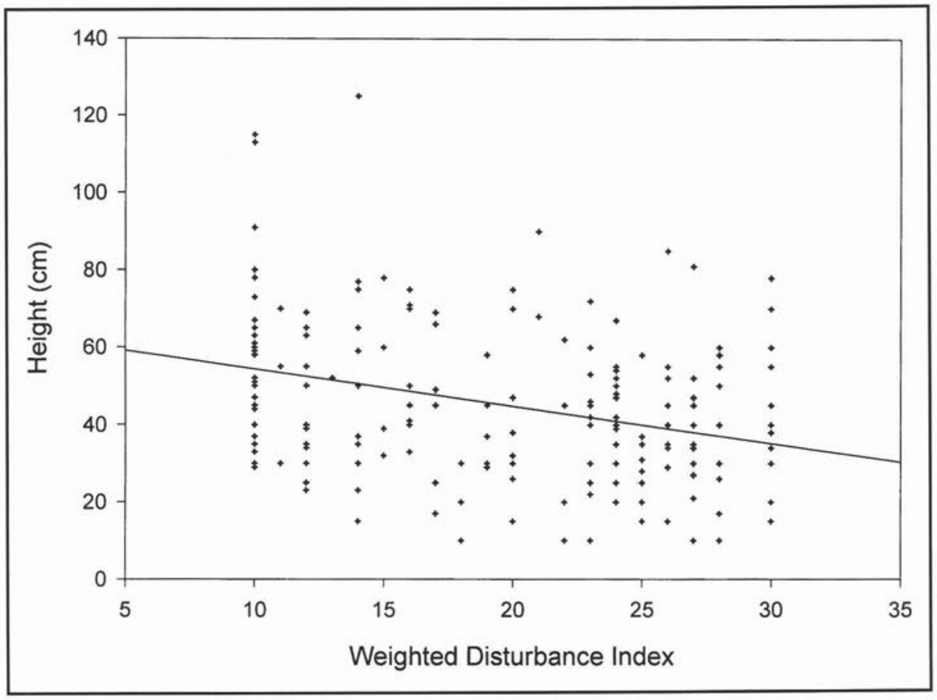

Fig. 1. Mean height of dominant aspen suckers related to weighted soil disturbance index – Marsh Grass site. Height = 63.8 – 0.95 × Disturbance Index; ($p < 0.001$, $r^2 = 0.10$).

Table 5. Proportion of area stocked, mean sucker density, and mean height of dominant suckers

Site	Stocked (%)	Density (k ha^{-1})	Height (cm)
Marsh Grass	55	9	45
West Branch	92	34.5	97
Beaver Pond	83	23.8	101

Branch site, where the trees were felled and limbed with chainsaws, the operator restricted the skidder to the plowed trails, parked it at a location near several stems, attached a choker to each, and winched them to the skidder, thus minimizing the area trafficked by the skidder.

Lateral movement of water is critical to maintaining productivity of level sites with fine textured soils. Rutting and puddling disrupts the hydrologic integrity of these soils, decreases site productivity, and the effects are likely to persist for decades (Grigal 2000). Internal soil drainage was classified as well-drained on the Marsh Grass site, moderately well-drained on the West Branch, and somewhat poorly-drained on the Beaver Pond (Table 1). Prior to logging, we expected that the amount and severity of site disturbance also would be in that order and planned our sampling intensity accordingly (Table 3). Ironically, the greatest amount of severe disturbance, primarily due to rutting and puddling, occurred on the well-drained and most productive Marsh Grass site with the least disturbance on the somewhat poorly-drained and less productive Beaver Pond site (Table 3). Thus, on these sites, type and size of equipment and operator practices were more important in creating heavy site disturbance than were the inherent soil properties.

Aspen Regeneration

Probable reasons for the differences in aspen regeneration differ for each stand. The 45% of the Marsh Grass site lacking aspen suckers (Table 4) can be explained by the heavy site disturbance on 38% of the area (Table 3), and by the 54% of initial basal area comprised of associated species (Table 2) that tended to be aggregated in patches. Damaged root systems and disrupted internal soil drainage resulted in ponding of surface water and saturated soils well into the growing season. Clearcutting eliminated the major source of evapotranspiration and prolonged the duration of inadequate soil aeration. This combination of conditions severely reduced the density and first-year growth of aspen suckers. The 8% of the West Branch site with no suckers is due mainly to the temporary road through the site, to concentrations of short logs along the road, and occasionally to deep slash where the tops of two or more trees were felled upon each other. Although the maple and other associated species made up 48% of the merchantable basal area, they tended to be distributed throughout the stand rather than in groups or patches, so probably had minimal effects on aspen root distribution. Most of the 17% of the Beaver Pond site without aspen stocking is due to sample points located in or near the poorly drained depressions initially occupied by sedges, alder, black ash, and red maple with few, if any, aspen roots present to produce suckers.

The detrimental effects of heavy disturbance, primarily rutting (Table 3), also are illustrated by the differences in areas with less than 15 000 suckers per ha (6 k ac^{-1}), averaging 25% on the West Branch and Beaver Pond sites and 37% on the Marsh Grass site (Table 4). The mean values for percent stocking (Table 5) are optimistic for two reasons. First, if a single sucker was present on any 5-m^2 plot (2 k ha^{-1}), it was considered "stocked." Secondly, most suckers develop the first growing season following winter harvest and stand density gradually declines in succeeding years (Perala 1984, Peterson and Peterson 1992 [Table 6]). Thus, the area presently considered as stocked is more likely to decline than to increase in the future.

The sucker density values (Table 5) are the means over each entire site. 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. Using these standards, 82% of the Marsh Grass site is either non-stocked, or sucker density is inadequate, and mean sucker density is adequate on the West Branch site. Excluding the poorly-drained areas on the Beaver Pond site would increase mean sucker density to near 30 k ha^{-1}. Aspen productivity on the Marsh Grass site was reduced additionally by the decreased height growth of the suckers (Table 5) which in turn, was significantly related to the weighted disturbance index (Fig. 1). The variation in these data is large and the regression explains a relatively small proportion of the total ($r^2 = 0.10$) for several reasons. First, the height data represent the largest sucker on each plot rather than the population mean; secondly, because most of the plots included more than one disturbance class; and additionally, due to variation in variables that were not measured, including root damage, soil temperature and aeration, and clonal variation in sucker initiation. However, the data clearly illustrate a trend of decreasing sucker height with increasing site disturbance.

Management Implications

Early results from these case histories illustrate several points applicable to management of fine-textured soils in the northern Great Lakes region: (1) When soils are not frozen, deep snow cover provides little, if any, protection against soil compaction and rutting. This was illustrated by an average 10% increase in soil bulk density in the nearby LTSP installation (unpublished data on file) and by the visible soil disturbance on these sites (Table 3). These heavily disturbed areas – roads, trails, landings, and compacted and/or rutted areas – essentially are removed from the aspen-producing land base. (2) Contrary to popular belief, clearcutting of aspen-dominated stands does not always assure prompt and adequate regeneration (Navratil 1991). Inadequate sucker density is most common on level sites with fine-textured soils; these are likely to remain cold, wet, and oxygen-deficient well into the growing season (Bates *et al.* 1990, 1993). Moreover, few if any, aspen roots are likely to be present on those portions of a site occupied by associated species, particularly when they occur in groups or patches. (3) Managers should specify the type, size, and timing of harvest equipment used, based on ecological classification units and site conditions at the time of harvest. Use of large, heavy equipment should be avoided when soils are excessively moist, and soil strength is low. (4) In stands with a substantial component of associated species, managers should consider reserving the immature conifer and hardwood growing stock (Navratil *et al.* 1994). This could provide both soil management and silvicultural advantages. 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 resulting in less disruption of ecosystem functions. Provided the root systems are not damaged by severe soil disturbance, aspen suckers will be free to develop on those portions of the site initially occupied by aspen. Suckers are not needed on those portions of the site occupied by the associated species.

Further research

The extent of soil disturbance measured on the Marsh Grass site was due to a combination of circumstances and greatly exceeded the amount that is normally encountered or tolerated by the Ottawa National Forest. Additional research will attempt to quantify relations between soil water content, soil strength, static ground pressure of logging equipment, and their effects on soil disturbance, in order to develop predictive parameters and mitigation measures.

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