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SOIL DISTURBANCE DURING FOREST HARVESTING AND RENEWAL

Submitted by

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Abstract

Information is presented on soil surface conditions following forest harvesting and site preparation in selected areas of the Fundy Model Forest. The study included (1) a post-harvest survey, conducted within 1 year from cutting and (2) a resurvey of the same blocks after site preparation one year later. The surveys involved point sampling along parallel transects with 500 to 2000 points per block. The blocks, 15 in total, were located mainly in the Fundy Highlands and Southern Uplands regions. The wood had been harvested by a mechanized shortwood system, whole-tree yarding and chipping, or a combination of both. Results of the first survey verified reductions in slash cover with whole-tree harvesting. From 23 to 43% of cutblock area was affected by machine traffic. This consisted of one-pass random movement, and light and heavy trails. The former was most common with whole-tree harvesting and the latter with the short-wood system. Rutting similarly increased with the shortwood system, affecting up to 9% of total cutblock area. Organic matter displacement and mineral soil exposure was small to insignificant, except on yarding areas. As intended, site preparation increased mineral soil exposure. This did not appear to promote erosion. Soil movement was generally negligible at low relief, but frequently noted in landscapes with rolling or hilly topography. Here, erosion developed in rutted and compacted soil of skidder or porter trails along slopes, and on yarding areas. Rills and gullies were present in an advanced case. Most of the cutblocks exhibited vigorous ground vegetation, which had effectively covered major portions of the cutovers by the

time of the second survey. Nevertheless, some of the changes recorded in these surveys pose a threat to future productivity and require further attention, in particular, the loss of nutrients and soil cover with increased slash removal in whole-tree harvesting, the likelihood of soil compaction on skidder and porter trails, and the increased erosion hazard in rutted and compacted soil.

Background

This project is concerned with soil conservation, which was recognized by the Canadian Council of Forest Ministers (1995) as one of the **criteria** for sustainable forest management. Although soil conservation has to be viewed from various aspects, the Council of Ministers further suggested that "the percentage of area harvested with significant soil disturbance, resulting in loss of productivity", be used as a measure **(indicator)** of shortcomings in soil conservation under prevailing management practices. Application of the indicator concept implies that potential impacts of soil disturbances on future productivity are well understood. But this is often not the case. What constitutes "significant soil disturbance" is a basic question that needs to be answered independently for each forest region and management regime. A review of the North American literature indicated a general lack of this kind of information for the Atlantic region of Canada (Krause 1998). The **primary objective** of the present project was, therefore, to identify and quantify adverse soil surface conditions arising from forest harvesting and site preparation for planting in the Fundy Model Forest region, and to evaluate the implications of such changes to future productivity. The newly gained information would offer an opportunity to re-evaluate and upgrade, if necessary, current forestry procedures to best management practices (BMPs), and provide a basis for developing simple, but realistic protocols for BMP compliance surveys.

Phase 1 (1999/00): Post-harvesting Survey

Eighteen blocks, harvested in the same year or fall of the preceding year, were surveyed during the summer of 1999. The blocks were located mainly in the Fundy Highlands and Southern Uplands regions where harvesting activities were concentrated in the past and current year (Fig. 1). Change in soil surface conditions was detected by recording patterns of slash disposal, patterns of machine traffic, organic matter displacement, frequency and depth of mineral soil exposure, and soil erosion. Classes and subclasses were defined for each variable (Appendix 1), and recorded at checkpoints, spaced at regular intervals on parallel transects. Depending on size, 500 to 2000 checkpoints were recorded on a cutblock. Harvesting included (1) a mechanized shortwood system, (2) whole-tree yarding and chipping and (3) a mixture of both. Also initially included in the survey were several small operations on private woodlots, employing chain saw and tractor or skidder.

Phase-1 results are summarized in a progress report, dated April 15, 2000 (Krause et al. 2000). In short, blocks with whole-tree yarding for chipping were left with a significantly reduced slash cover if compared to shortwood harvesting. Method of harvesting also resulted in different traffic patterns, with machine movement being extensive but light where trees were extracted for chipping, and typically concentrated in major trails under the shortwood system. Rutting was more frequent and deeper with the latter. The severity of rutting further varied with position in the landscape (Fig. 2). As expected, valley bottoms and foot of the slope were most susceptible to rutting. Dragging of whole trees resulted in minor displacement of organic matter and/or mixing of surface organic matter with mineral soil. Extensive displacement of organic matter with potential loss to productivity (Subclass F3) was limited to yarding areas. Mineral soil exposure between skid or porter trails was generally limited. In the worst case, about 1.2% of the total area of the cutblock was bare of organic matter (forest floor), logging slash or vegetation. Exposed soil was predominantly from the Ae and B horizons. Deep gouging into the C horizon was rare to non-existent. Some of the blocks exhibited incipient to light erosion, but soil loss was negligible during the first year following the cut. On-site chipping of wood yielded notable quantities of residue, which, if deposited in thick layers, inhibited re-vegetation.

Phase 2 (2000/01): Re-survey after site preparation

Project plans called for (1) an expansion of the post cutting surveys to cover different Site Districts and (2) a re-survey of the first set of blocks to determine further change in soil surface conditions by site preparation, and to monitor the progress of soil erosion. Having to cope with a limited budget, priority was given to resurvey and erosion monitoring. Operations on private woodlots were excluded from further study because of the small number of cutblocks initially available, and difficulties in locating new blocks. Fifteen of the 18 blocks, included in the 1999/00 report, were thus resurveyed in 2000.

Effects of site preparation

Nearly all of the areas resurveyed had been site prepared, involving the use of barrels and anchor chains, or a Bracke scarifier (Table 1). As intended, site preparation produced varies levels of **mineral soil exposure**. In the extreme case, the proportion of bare soil on the cutblock was raised from 0.6% after harvesting to 8.4% after site preparation (Table 2). Although among-block variation was high, mineral soil exposure was increased about 3% by site preparation on the average block. This consisted of discontinuous trenches and small patches, conforming to the concept of scarification in silvicultural terminology. In the majority of cases, the disturbance was shallow, exposing the Ae horizon and less frequently the B horizon (Fig. 3). Rarely was soil from the C horizon exposed. **Dumping and mounding** of soil was less frequently encountered than in the post-harvest survey. Presumably, soil in this classification was reworked during site preparation. The portion of checkpoints with **mixed organic and mineral soil** similarly decreased from the first to the second survey, which may also be explained by the reworking of surfaces during site preparation, and the rapid re-growth of the vegetation. Mineral soil exposure, attributable to site preparation, rarely led to any form of erosion.

Slash cover was consistently lower in the second survey. The reduction was greatest in originally thin deposits (Sub-class S1) while the coverage of heavy deposits showed more often than not a slight gain (Table 2). This can be attributed to site preparation, the primary purpose of which is to improve planter mobility by concentrating logging slash. Also, light logging slash was often concealed by the rapidly recovering ground vegetation. The re-survey further indicated increased coverage of blocks by **chipping residue,** suggesting some spreading and redistribution of deposits by site preparation equipment. However, most of the residue still existed in intermediate and deep deposits (Sub-classes C2 and 3), on which plant growth was scarce, if not lacking.

Erosion and sedimentation

Resurvey of cutblocks showed advances in soil erosion, if compared to results from the first (post-harvesting) survey (Table 2). While evidence of soil movement was entirely lacking on some blocks, locations of incipient and light erosion were not uncommon on the majority of remaining blocks. In some cases, rills and minor gullies had formed, indicating moderate erosion (see Erosion Classes, Appendix 1).

Erosion was most commonly associated with rutting. At fluctuating gradient, the increased force of channeled water resulted in a pattern of alternating denudation and inundation (Fig. 4A). Transport of sediment over long distance was induced by mineral soil exposure and compaction by machine traffic on strong slopes (Fig. 4B). Cases of advanced erosion and sedimentation were encountered on or near landings within rolling and hilly landscapes (Fig. 5). Sediment was delivered in channeled flow (Fig. 6A) to the foot of the slope (Fig. 6B). Depending on soil conditions and slope, the sediment was retained at such locations or moved further towards the watercourse in secondary erosion, with the potential for gully formation (Fig. 7).

Slope, obviously, was a key factor in determining soil movement upon disturbance. Erosion was absent or negligible on blocks with level to moderately sloping (<15%) terrain. An erosion hazard did not exist even if the grade rose occasionally to 30% in a predominantly level or undulating landscape. Moderate erosion, with the appearance of rills and minor gullies, was observed where strongly sloping (31-45%) terrain made up major portions of the cutblocks. On Block 7, for example, the proportion of the land affected by erosion rose from 0.2% at the time of the post-harvest survey to 2.3% in the following year (Table 2). At these levels of erosion, sediment was regularly found in depressed locations, at times in layers thicker than 10 cm.

Residual trees and re-growth of ground vegetation

As customary in forest harvesting of the region, trees were left in variable numbers on the surveyed cutblocks (Fig. 8). The cumulative crown projections of the remaining trees ranged from 2.6 to 15.4 % of the total cutblock area (Table 2). This kind of cover may be presumed to offer some protection to the exposed soil, lowering the incidence of erosion. However, such a beneficial effect was not apparent in the data compiled in Table 2.

At the time of the second survey, ground vegetation had efficiently established itself on most of the cutblocks (Table 2). Grasses prevailed at most of the sites, providing coverage upward to 22% of the block. Raspberry cover ranged from about 1 to 10%, and plants of the herbaceous group (ferns included for convenience), dominated on better sites. The vegetative groundcover was further broadened by abundant hardwood regeneration. Under favorable conditions, upwards to 50% of the cutblock area had been covered by vegetation, including locations with light to moderate slash cover and mineral soil exposure. Cutblocks with extensive ground vegetation appeared to have the lowest incidence of soil erosion.

Discussion

Survey of cutblocks revealed familiar patterns of change above and within soil surface horizons. Most obvious and subject to discussion here are: amount and distribution of logging slash, deposition of chipping residue, machine traffic and rutting, displacement of surface organic matter, mineral soil exposure, erosion and sedimentation, and.

Amount and distribution of logging slash

As pointed out previously, coverage of soil by slash was significantly reduced by extraction of whole trees for chipping compared to harvesting by the shortwood system (58 to 39% of total area). This trend of decreasing slash coverage gives an indication of the extra loss of nutrients with whole-tree harvesting. The problem is aggravated where trees are harvested in full foliage. Slash also has a mulching effect, protecting soil surface and seedlings from drying winds and pounding rain. The beneficial effect of logging slash was demonstrated by Entry et al. (1986) who investigated the microbiological activity in soil of clearcuts in the Rocky Mountain region. These advantages may be lost if slash is concentrated in heavy deposits. As shown by the post-harvesting survey data, slash existed in heavy deposits (>50 cm) on 2 to 14 % of cutblock area, with most of the variation accounted for by harvesting method. It is interesting to note that the vegetation, including soft and hardwood regeneration, established itself readily, if not preferentially, under light slash (<20 cm), and was also common under moderate slash (<50 cm), but rare to non-existent under deep deposits. This coincides with earlier concerns that heavy concentration of slash results in uneven stocking and possibly loss of productivity if the succeeding forest is to be regenerated naturally.

Chipping residue

As shown in the post-harvest survey, chipping residues covered from 1.1 to 10.1% of cutblock areas. Most of the residue had been deposited at >10 cm depth. Little, if any vegetation was recorded at these locations in the second survey, and planted trees were struggling or had failed to establish themselves. This coincides with the observations of Corns and Maynard (1998) with aspen chip residues from Albertan forests. Vegetative cover and aspen suckering was markedly reduced on soil covered three years earlier with a 10-cm thick layer of residue. They tentatively recommended that residue from poplar harvest with remote or satellite chipping be disposed off by distribution over the cutblock in layers of about 5 cm depth.

Machine traffic, soil compaction and rutting

Depending on method of harvesting, from 23 to 43% of cutblock area was affected by machine traffic. Two contrasting patterns were recognized: (1) predominantly single-pass movement, with common light trails, but few heavy trails, and (2) concentrated traffic in heavy trails and correspondingly reduced random traffic. The former was characteristic of harvesting with on-site chipping and the latter of the short-wood system. The greatest increase in soil density normally occurs with the first few passes of a vehicle and diminishes with each additional pass (Froehlich and McNabb 1984). Judging from the particle size distribution of the fine earth, soils in the general area have intermediate or higher compressibility. However, high coarse fragment content imparts increased soil strength and resistance to compaction. These soils further have thick forest floors and shallowly developed root systems both capable of absorbing some of the applied force from wheeled or tracked vehicles. It is improbable, therefore, that the extensive random traffic, as observed on the whole-tree harvested hardwood blocks, has caused soil compaction detrimental to future productivity. This suggestion is supported by the rapidly developing ground vegetation across most of the cutblocks. Not overlooked, however, should be the problem of rutting, arising from random movement of skidders on wet soils (Fig. 9).

Damage to soil by compaction and rutting was readily apparent on repeatedly traveled trails. According to the post-harvest survey, soil was shallowly (5-10 cm) rutted on 0.4 to 3.3% of total cutblock area. This generally implies compaction critical to plant establishment and growth. Additional 0.3 to 3.4% and 0.2 to 3.2% of total cutblock area showed intermediate (11-20 cm) and deep (>20 cm) rutting, respectively. As shown in the previous report, rutting was most frequent and deepest on level terrain, but also occurred on gentle to moderate slopes. This should not be unexpected given the low subsoil permeability and common seepage condition in New Brunswick soils.

No measurements were made of changes in bulk density, but the literature contains clear examples of short and long-term reductions in tree growth on compacted skidroads (Smith and Wass 1979; Wert and Thomas 1981; Corns 1988). In deeply rutted soil, root activity is impaired by both compaction and loss of exploitable soil volume. Rooting and plant establishment can also be hindered in puddled soil. This condition was occasionally encountered at locations of heavy machine activity on water-saturated soils.

Aiming to minimize the impact of logging equipment on soil quality, Froehlich and McNabb (1984) emphasized the need for designing a system of skid trails prior to the cut. They concluded that harvesting from designated skidtrails is the best option for preventing productivity loss due to soil compaction. They further indicated that preplanned skidtrails can economically be held to about 10% of the logged area.

Erosion control

According to the results of the survey, an erosion hazard exists after logging in terrain with rolling and hilly topography. Sediment is moved in channel flow developing in rutted and compacted soils of skidder and porter trails, and on yarding areas with soils of low permeability. As a result, soil materials may be relocated within the cutblock area and sediment may be leaked into adjacent watercourses. Although small if compared to sediment input from haulroads (example from general survey area is shown in Fig. 10), run-off from skidtrails and yarding areas should not be ignored. Favorable to erosion control are the rapidly developing ground vegetation under New Brunswick soil and climatic conditions, the predominantly matted organic matter of the forest floor and the generally high coarse fragment content of New Brunswick's soils. However, prohibiting soil movement in the early critical period, i.e. 1-3 years after the cut, requires precautionary measures. For example, guidelines, well known in the literature, prohibit skidtrails on long continuous grades or grades in excess of 25 to 30% (Rothwell 1978). Instead, trails are to be located along contour lines or diagonally across the slope. If trails are unavoidable on strong slopes, water bars or similar structures are called for to divert water into undisturbed areas. Also, the total length of skidtrails can be shortened and soil loss minimized by careful choice of yarding areas.

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Table 1. List of cutblocks included in second survey (2000) following site preparation.

#	Cutblock Location	Coordinates1 Latitude/Longitude	Cover Type	Land Ownership	Size of cutblock ha	Type of operation	Method of site preparation2
4	Mechanic Settlement	45o43.692' / 65o13.015'	IH+yB+S/F	Crown	8	Shortwood	none
5	Anagance	45o51.762' / 65o17.116'	IH+S/F+wP	Crown	40	Shortwood/Chipping	barrels & chains
6	Quiddy River	45o36.103' / 65o13.652'	yB+IH+rS	Crown	31	Chipping	barrels & chains
7	Shepody Road East	45o42.375' / 65o02.538'	IH+yB+rS	Freehold	15	Shortwood/Chipping	barrels & chains
8	Ross Corner	45o44.314' / 65o03.022'	T&IH+rS	Freehold	14	Shortwood	Brakke scarifier
9	Point Wolfe River	45o38.041' / 65o33.590'	T&IH+rS	Crown	14	Chipping	barrels & chains
10	Teahans Corner	45o38.041' / 65o33.590'	IH+yB+rS	Crown	22	Shortwood/Chipping	barrels & chains
11	Shepody Road West 1	45o40.610' / 65o07.795'	rS+IH+yB	Freehold	7.5	Shortwood	barrels & chains
12	Shepody Road West 2	45o40.379' / 65o07.501'	T&IH	Crown	2	Chipping	none
13	Shepody Road West 3	45o40.484' / 65o06.944'	T&IH	Crown	25	Chipping	barrels & chains
14	Little Salmon River	45o36.179' / 65o14.130'	rS+IH+yB	Freehold	16.5	Shortwood/Chipping	barrels & chains
15	Church Corner	45o44.914' / 65o03.441'	T&IH+rS	Freehold	25.5	Shortwood/Chipping	Brakke scarifier
16	Church Hill 1	45o42.346' / 65o06.345'	T&IH+rS	Freehold	3.75	Chipping	none
17	Church Hill 2	45o42.834' / 65o05.841'	IH+yB+rS	Crown	2	Chipping	Brakke scarifier
18	Spring Hill Brook	45o57.864' / 65o25.532'	IH+yB+rS	Freehold	5	Shortwood	barrels & chains

1 Approximate locations of survey grid starting points; 2 needs verification

Table 2. Soil surface conditions on cutblocks 4 to 11: Results of first and second surveys
(Cutblocks 1-3, representing private woodlots, not resurveyed; data from Cutblocks 12-18 not yet evaluated; blocks with highest levels of erosion highlighted).

		CUTBLOCK															
Parameter	**class**	**4 survey**		**5 survey**		**6 survey**		**7 survey**		**8 survey**		**9 survey**		**10 survey**		**11 survey**	
		1	**2**	1	**2**	1	**2**	1	**2**	1	**2**	1	**2**	1	**2**	1	**2**
Number of check points		737	1051	1850	1882	1510	1511	930	1123	1115	1174	1436	1496	1485	1382	1013	929
		% check points															
Organic matter displacement	1		0.3		0.7		4		1.7		2.0		1.9		3.3		3
	2		0		0.1		1.3		1.2		0.5		0.9		2.5		1.1
	3		0		0.1		0.5		0.5		1.0		0.1		0.5		0.4
	Total	**0.5**	**0.3**	**4.4**	**0.9**	**6.1**	**5.8**	**1.2**	**3.4**	**0.6**	**3.5**	**5.1**	**2.9**	**6.8**	**6.3**	**2.7**	**4.5**
Mixing (organic +min. soil)		**10**	**0**	**4.5**	**0.9**	**9.7**	**8.6**	**5.2**	**1.9**	**6.4**	**0**	**4.9**	**14.3**	**8.4**	**5.8**	3.4	1.6
Mineral soil exposure	1	0.3	0.5	1.2	1.4	0.3	2.9	0.2	0.6	0	2.2	0.2	0.9	0.1	5.2	0	2.1
	2	0.8	0.3	0.6	0.4	0.7	1.1	0.2	1.1	0.1	1.9	0.2	0.7	0.5	3.2	0	1.3
	3	0.1	0	0	0	0.0	0	0	0.0	0	0	0	0.1	0	0	0	0
	Total	**1.2**	**0.8**	**1.8**	**1.8**	**1.0**	**4.0**	**0.4**	**1.7**	**0.1**	**4.1**	**0.4**	**1.7**	**0.6**	**8.4**	**0**	**3.4**
Mounding	1	1.4	0.5	0	0.5	1.7	0.4	4.2	0.2	5.7	1.5	1.1	0.4	2	0.7	1	1.4
	2	1.1	0.3	1	0.4	1.3	0.3	0.5	0.1	0.7	1.5	0.8	0.3	0.4	1.4	0.3	0.6
	3	0	0		0.1		0.1	0	0	0	0.4	0	0	0	0.4		0.1
	Total	**2.5**	**0.8**	**1.0**	**1.0**	**3.0**	**0.8**	**4.7**	**0.3**	**6.4**	**3.4**	**1.9**	**0.7**	**2.4**	**2.5**	**1.3**	**2.1**
Rutting	1	3.1		1.1		2.5		2.3		3.3		1.1		3.3		1	
	2	2.2		0.9		1		1.7		3.4		0.7		1.7		0.9	
	3	2.7	0.6	0.9		0.6		2.6		3.2		1		0.9		0.2	
	Total	**8.0**	**0.6**	**2.9**	**0.9**	**4.1**	**1.3**	**6.6**	**2.4**	**9.9**	**7.6**	**2.8**	**1.9**	**5.9**	**2.5**	**2.1**	**3.6**
Erosion	1			0.0	0.1	0.0	0.1	0.2	0.4	0.0	0.0	0.0	0.0	0.1	0.4	0	0.4
	2			0.1	0.1	0.1	0.1	0	1.3	0.0	0.0	0.0	0.0	0.1	0.6	0.2	0.2
	3			0.0	0.0	0.0	0.0	0	0.6	0.0	0.0	0.0	0.0	0	0.1	0	0.6
	Total	**0.0**	**0.0**	**0.1**	**0.2**	**0.1**	**0.2**	0.2	**2.3**	**0.0**	**0.0**	**0.0**	**0.0**	**0.2**	**1.1**	**0.2**	**1.2**
Sedimentation	1	0.3		0.1	0.0	0.1	0.0	0.1	0.1	0.1	0.0	0.0	0.0	0.1	0	0.4	0.2
	2	0.0		0.0	0.2	0.0	0.1	0.1	0.3	0.0	0.0	0.0	0.0	0	0.2	0	0.3
	3	0.0		0.0	0.1	0.0	0.0	0	0.2	0.0	0.0	0.0	0.0	0	0.6	0	0.6
	Total	**0.3**	**0.0**	**0.1**	**0.3**	**0.1**	**0.1**	**0.2**	**0.6**	**0.1**	**0.0**	**0.0**	**0.0**	**0.1**	**0.8**	**0.4**	**1.1**
Slash	1	32.0	15.3	30.0	18.8	18.6	11.0	25.9	17.6	31.0	31.0	25.3	12.5	31.3	16.7	38.1	24.9
	2	15.5	15.9	13.3	8.9	10.3	5.8	16.7	12.4	19.5	13.2	7.6	9.4	8.9	9.2	15.3	14.7
	3	7.6	10.8	2.3	3.3	2.5	4.8	3.7	6.0	3.3	2.2	1.8	2.3	1.7	6.7	2.7	5.6
	Total	**55.1**	**42.0**	**45.6**	**31.0**	**31.4**	**21.6**	**46.3**	**36.0**	**53.8**	**46.4**	**34.7**	**24.2**	**41.9**	**32.6**	**56.1**	**45.2**
Chipping residue	1			0.8	1	1.7	2.2	0	0.1	0.0	0.0	2.3	1.3	0.6	0.8	0	0
	2			1	1.5	2.2	2.4	0.8	0.2	0.0	0.0	1.3	2.5	0.6	1.2	0	0
	3			0.4	1.1	0.5	2.3	0.3	0.7	0.0	0.0	0.6	1.1	0	0.5	0	0
	Total	0	0	**2.2**	**3.6**	**4.4**	**6.9**	**1.1**	**1.0**	**0.0**	**0.0**	**4.2**	**4.9**	**1.2**	**2.5**	**0**	**0**
Regrowth																	
grass			12.1		22.5		8.7		7.7		(2)		7.7		6.2		7.4
raspberry			6.2		1.3		6.8		6.7				9.7		4		1.4
herbaceous			13.6		9		10.0		5.8				7		3.1		2.6
ericaceous			3.1				0.5		1.4				0.3		0		0
shrub (1)					0.7				0.4				0.3		0.3		0
hardwood regen.			4.2		11.3		2.3		2.3				1.5		0.7		0

Appendix

Classes and sub-classes of selected variables for assessing soil conditions after forest harvesting and site preparation.

Variable		Class			sub-subclass		
S	Slash	1	light[1]	20 cm to discontinuous	a	fine[2]	< 5 cm
		2	moderate	20-50 cm	b	medium	5-10 cm
		3	heavy	>50 cm	c	coarse	>10 cm
C	Chipping residue	1	shallow	<10 cm			
		2	intermediate	10-20 cm			
		3	deep	>20 cm			
T	Traffic	1	light	single pass (random movement)			
		2	intermediate	two or several passes (light trail)			
		3	heavy	many passes (major trail)			
R	Rutting	1	shallow	5-10 cm			
		2	intermediate	11-20 cm			
		3	deep	>20 cm			
M	Mineral soil exposure	1	shallow	Ae horizon exposed	a	dragging trees	
		2	intermediate	B horizon exposed	b	blading[3]	
		3	deep	C horizon exposed[4]	c	other	
N	Mounding	1		dumping of soil, turning of tracked machines etc.			
		2		uprooting of stumps			
X	Mixing	1		Forest floor organic matter and mineral soil effectively mixed			
F	Forest Floor	1	small patch (<3 m^2)	Surface organic matter largely removed,			
		2	interm. patch (3-25 m^2	with remnants only of H horizon remaining,			
		3	large patch (>25 m^2)	but Ae horizon not visible on most of the patch			
E	Erosion	1	incipient	concentration of coarse fragment recognizable			
		2	light	coarse fragments concentrated across surface			
		3	moderate	rills and/or minor gullies present			
		4	heavy	gullies deeper than 50 cm			
S	Sedimentation	1	light	<5cm, discontinuous	a	silt & fine Sand	
		2	moderate	5 -10 cm, continuous	b	humic matter	
		3	heavy	>10cm deep deposit	c	mineral & organic	

1 As determined by depth of deposit;

2 According to prevailing diameter class of logging slash;

3 As, for example, removing surface soil for yarding areas or preparation of trails;

4 At least to 20 cm depth.

Figure Captions

1. Approximate location of surveyed cutblocks (to be supplied later).

2. Effect of slope on rutting (A) and traffic pattern on a cutblock with mixed shortwood and chipping operation, Anagance (Slope classes: level, 0-2%; gentle. 3-9%; moderate, 10-15%; strong, 16-45%).

3. Exposure of mineral soil by site preparation (% of total cutblock area).

4. Soil erosion initiated by rutting on moderate slope (A) mineral soil exposure and compaction on skidtrail on a strong slope (B).

5. Sheet erosion on former yarding area.

6. Sediment delivery in channeled flow (A) to the foot of a slope (B).

7. Secondary erosion with potential for gully formation.

8. Residual trees may provide limited cover, but did not appear to influence patterns of erosion as observed on some cutblocks.

9. Deep ruts left after a single pass of skidder or porter.

10. Massive soil movement following haulroad failure near Cutblock 10

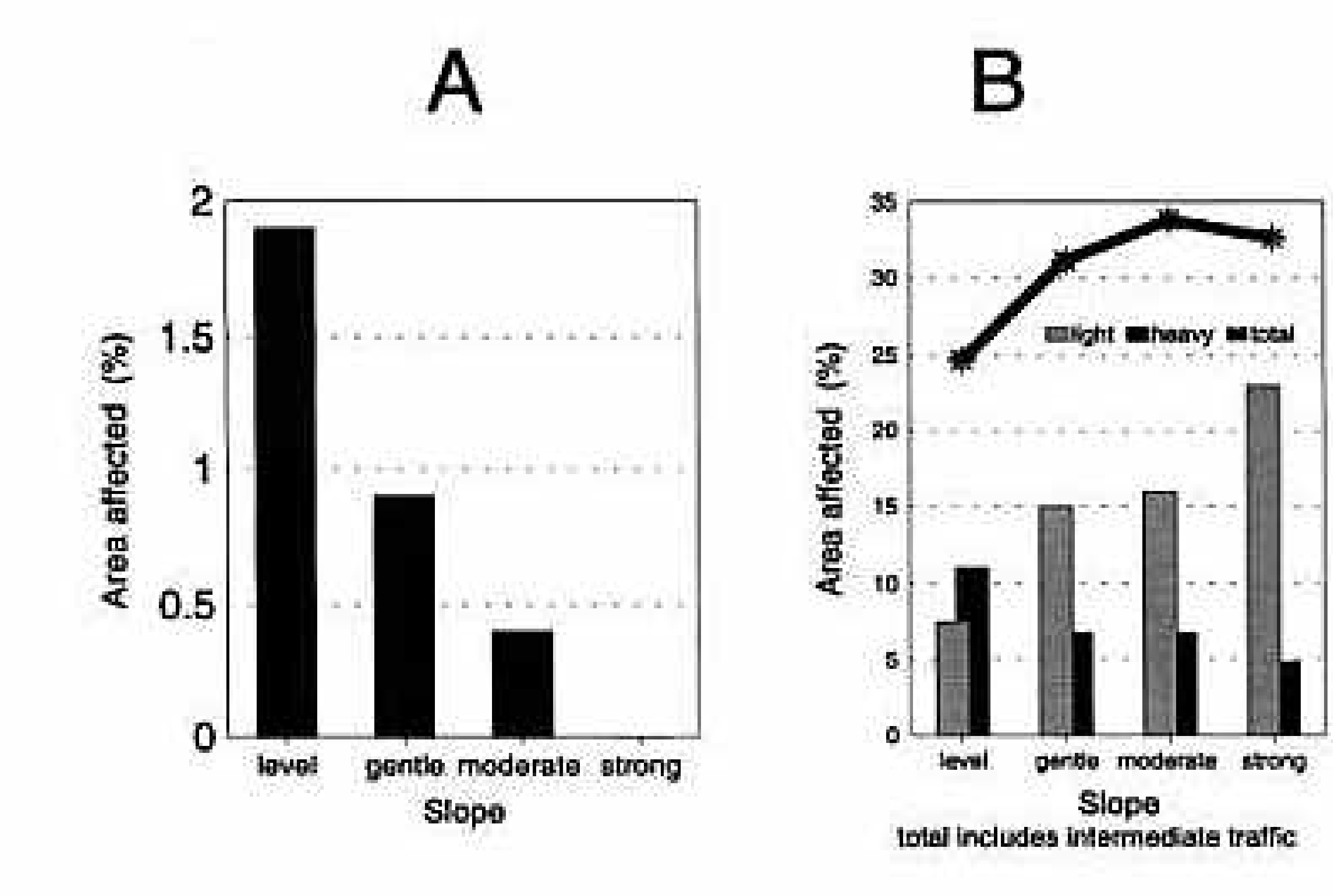

Figure 2. Effect of slope on rutting (A) and traffic pattern on a cutblock with mixed shortwood and chipping operation, Anagance (Slope classes: level, 0-2%; gentle. 3-9%; moderate, 10-15%; strong, 16-45%).

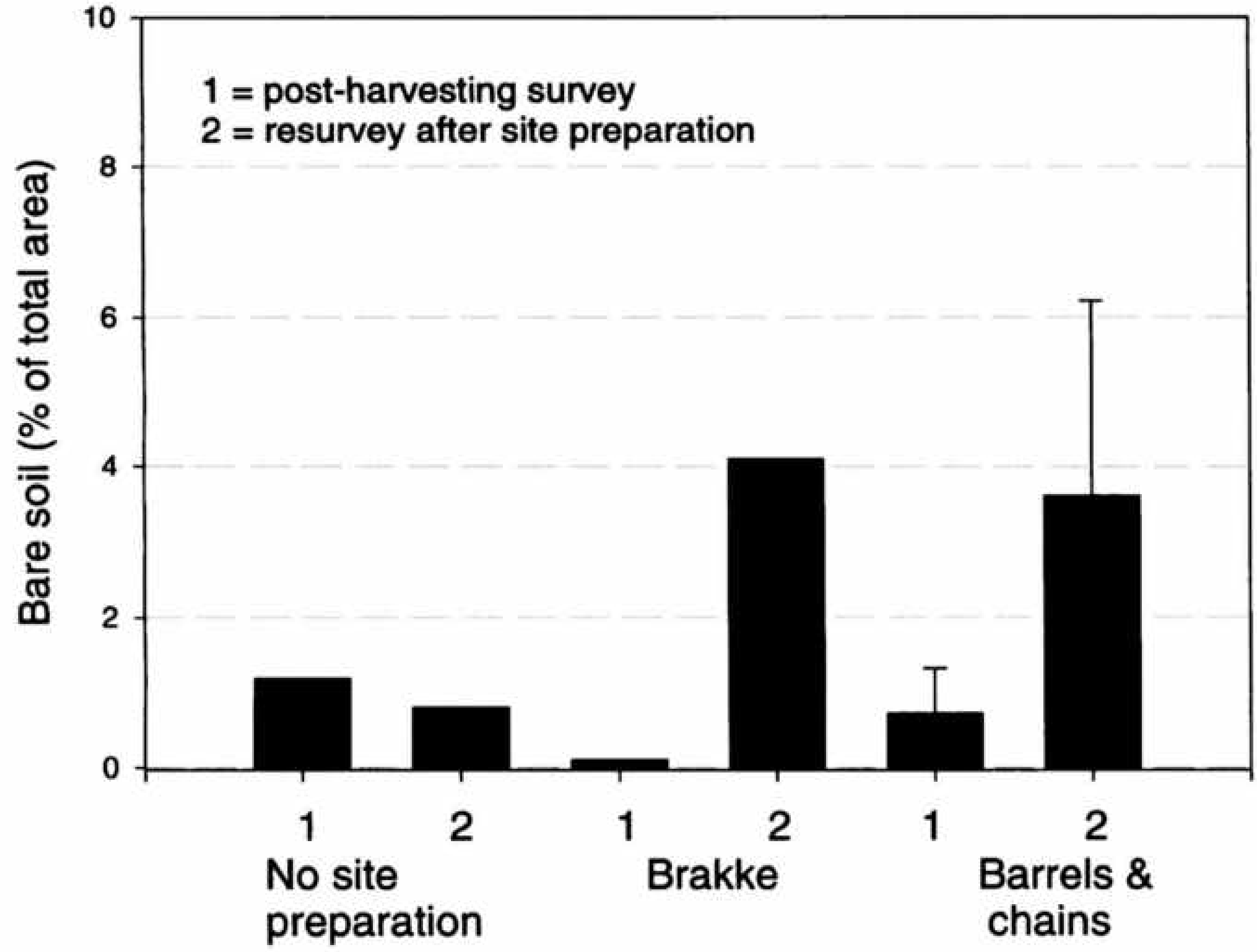

Figure 3. Exposure of mineral soil by site preparation (% of total cutblock area).

Figure 4a. Soil erosion initiated by rutting on moderate slope (A) mineral soil exposure and compaction on skid trail on a strong slope (B).

Figure 4b. Mineral soil compaction on skidtrail on a strong slope (B); note lack offorest regenration on skid trail.

Figure 5. Sheet erosion on former yarding area.

Figure 6a. Sediment delivery in channeled flow.

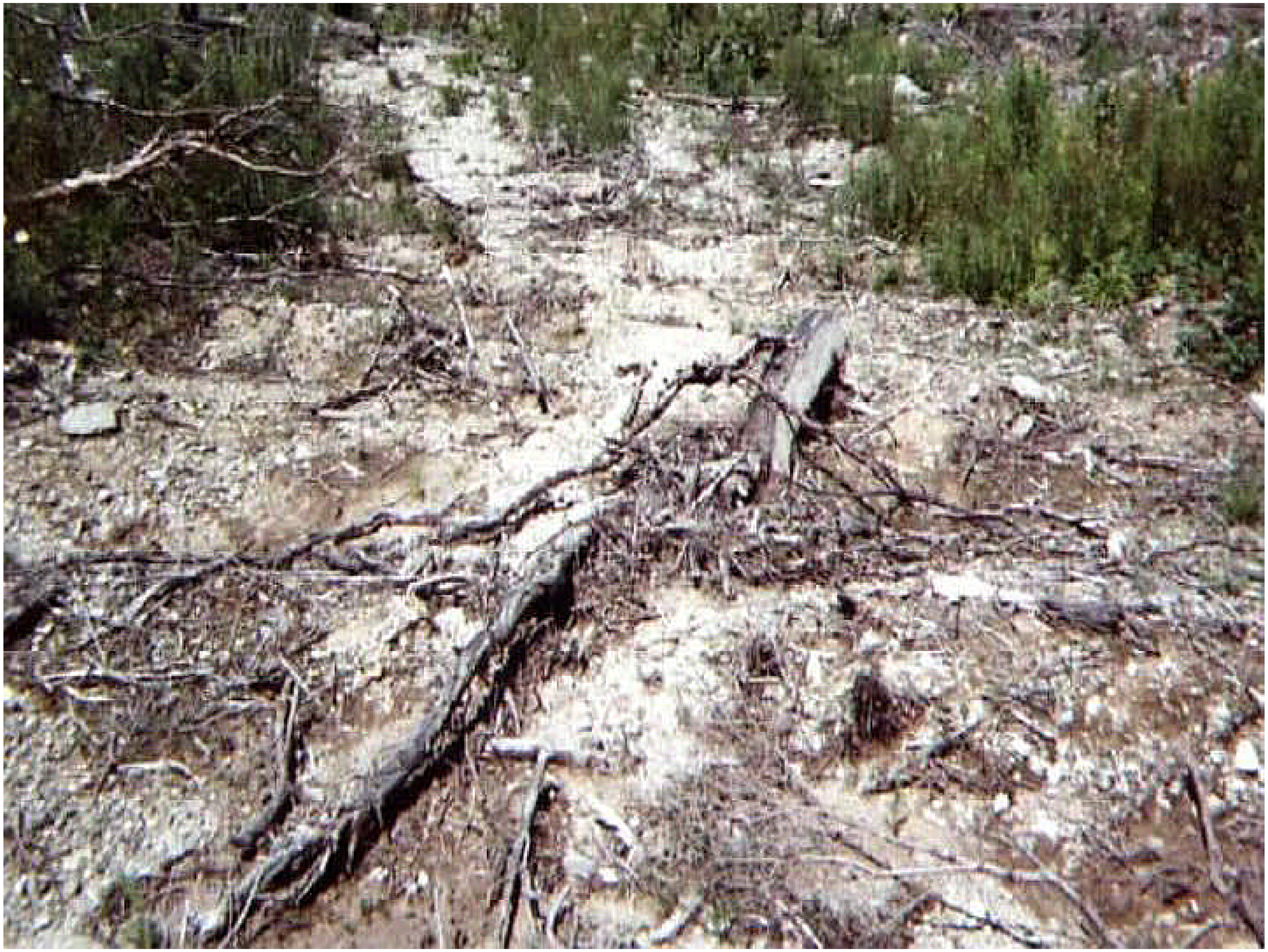

Figure 6b. Sediment delivery from channeled flow to bottom of slope.

Figure 7. Major secondary soil erosion, including major gully formation.

Figure 8. Residual trees may provide soil cover, but do not always prevent soil erosion, especially where forest floor layers are thin. Also, long slopes with silty soil exposed could lead to major soil erosion events along that road.

Figure 9. Residual trees may provide soil cover, but do not always prevent rutting. This is a deep rut left after a single pass of skidder or porter.

Figure 10. Massive soil movement following haul road failure near Cutblock 10.