Impacts of a stump uprooting operation on properties of a calcareous loamy soil and on planted seedling performance

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R.B. Smith and E.F. Wass

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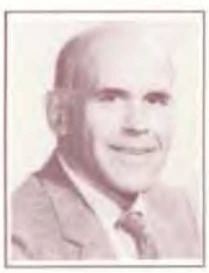
About the Authors



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Contents

Abstract

Six hundred Douglas-fir (*Pseudotsuga menziesii*) and 600 lodgepole pine (*Pinus contorta* var. *latifolia*) seedlings were planted on seven plots in a cutover north of Golden, British Columbia, to ascertain the impacts of stump uprooting operations conducted to control the spread of root disease on site productivity. Equal numbers of trees were planted on tracks and deposits created during stump uprooting, and on undisturbed ground, as confirmed by the presence of an intact humus layer. Soil characteristics were measured initially on disturbed and undisturbed portions of the cutover, and tree growth was monitored for eight growing seasons after planting. Foliage was sampled for nutrient content after the fifth year.

Seventy-two percent of the area was disturbed by the stump uprooting operation, about equally divided between gouges (mainly tracks) and deposits. The top 20 cm of soil in tracks was on average 23% denser and 68% less penetrable than the equivalent layer of undisturbed mineral soil. In contrast, deposits were about equal in density to undisturbed soil and, at depths of 15 and 20 cm, were about half as resistant to penetration. The presence of free carbonates in the surface mineral soil increased with increasing depth of disturbance from 2% of spots sampled in undisturbed soils to 41% of spots with very deep (>25 cm) gouges or deposits.

Douglas-fir seedlings planted in tracks were the smallest after eight growing seasons, significantly less in height and diameter (12-14%) than for seedlings planted in deposits or undisturbed soil. After 8 years, lodgepole pine seedlings planted in tracks were on average significantly (12%) shorter than those planted on undisturbed ground. The two species planted in tracks contained 23-25% less volume, but differences were not statistically significant. Growth rates for seedlings planted in deposits were similar to those for undisturbed ground. Vegetative cover increased more slowly on tracks than deposits and included a number of species not frequently found on deposits or undisturbed ground.

Comparisons of productivity impacts resulting from uprooting stumps and from other forestry operations are made using research results obtained by the authors and other researchers.

Résumé

Six cents semis de douglas taxifoliés (*Pseudotsuga menziesii*) et 600 autres de pin tordu (*Pinus contorta* var. *latifolia*) ont été plantés sur 7 lots d'une coupe située au nord de Golden, en Colombie-Britannique, pour vérifier si des opérations d'essouchage destinées à limiter la propagation de la maladie des racines ont des incidences sur la productivité des sites. Des nombres égaux d'arbres ont été plantés sur les traces de roues et les dépôts créés au cours de l'essouchage, ainsi que sur du sol non dérangé, comme le montrait la présence d'une couche intacte d'humus. Les caractéristiques du sol ont été mesurées au tout début sur des portions dérangées et non dérangées de la coupe, et la croissance des arbres a été surveillée pendant 8 saisons de croissance consécutives après la plantation. On a échantillonné le feuillage pour déterminer sa teneur en nutriments après la cinquième année.

Soixante-douze pour cent de la surface a été perturbée par l'opération d'essouchage, divisée à peu près également en sillons (principalement des traces de roues) et des dépôts. La couche supérieure de 20 cm du sol des traces était, en moyenne, 23 % plus dense et 68 % moins pénétrable qu'une couche équivalente de sol minéral non dérangé. Par contre, dans le cas des dépôts, la densité était à peu près égale à celle observée dans le sol non dérangé et, à des profondeurs de 15 à 20 cm, la résistance à la pénétration était d'environ la moitié. La présence de carbonates libres dans le sol minéral superficiel augmentait proportionnellement à la profondeur du sol déplacé, passant de 2 % aux endroits échantillonnés dans le sol non dérangé à 41 % dans les dépôts ou les sillons très profonds (>25 cm).

Les semis de douglas taxifoliés plantés dans les traces étaient les plus petits après 8 saisons de croissance. Leur taille et leur diamètre étaient significativement inférieurs (12 à 14 %) à ceux des semis plantés dans les dépôts ou dans le sol non dérangé. Après 8 ans, les semis de pin tordu plantés dans les traces avaient une hauteur moyenne significativement inférieure (12 %) à celle des semis plantés dans le sol non dérangé. Les deux espèces plantées dans les traces avaient un volume inférieur de 23 à 25 %, mais les différences n'étaient pas statistiquement significatives. Les taux de croissance des semis plantés dans les dépôts étaient semblables à ceux observés pour le sol non dérangé. La couverture végétale augmentait plus lentement dans les traces que dans les dépôts et comportait un certain nombre d'espèces qui n'étaient pas trouvées fréquemment dans les dépôts ou le sol non dérangé.

À l'aide des résultats obtenus par les auteurs et ceux d'autres chercheurs, des comparaisons sont faites entre l'essouchage et d'autres opérations forestières pour ce qui est de leurs incidences sur la productivité du site.

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We thank Dr. John Muir, Pathologist, British Columbia Ministry of Forests (BCMF), Victoria, for bringing the stump uprooting operation to our attention. The assistance of Al Pollard, Resource Officer Silviculture, BCMF, Golden District, in establishing the plantation and providing help to monitor seedling survival and growth, was greatly appreciated. Larry Price, BCMF, Nelson Region, provided information on the site and on the conduct of forestry operations. We are grateful for the interest taken by these gentlemen in the progress of the study. Analyses of soil for organic carbon, total nitrogen and carbonate equivalence were conducted partly by Pacific Soils Analysis, Inc., Vancouver, and partly by staff of the Pacific Forestry Centre (PFC) under the direction of Ann Van Niekerk. The latter group also conducted the foliage nutrient analyses. Dorthe Jakobsen, Geological Survey Branch, Victoria, identified the bedrock samples. Thanks also go to Ian Moss and John Senyk (PFC) and Gerry Davis (BCMF, Nelson Region) for thorough reviews and to PFC staff Steve Glover for editorial assistance, and Dan Dunaway for graphics and design. Partial funding for the eighth-year measurement was provided by the BCMF through its Sustainable Environment Fund.

1.0 INTRODUCTION

Stump uprooting is a silvicultural operation conducted to control the spread of root diseases to new regeneration (Wallis 1976; Morrison 1981; Thies 1984). Recent evidence indicates that the procedure has been successful in reducing infection of planted stock (Bloomberg and Reynolds 1988; Morrison *et al* 1988). Concerns over soil damage (Smith 1981; Thies and Russell 1983) have been borne out in some but not all sites (Smith and Wass 1991).

An opportunity to study the impacts of stump uprooting on soils and site productivity arose in 1982 when a stand, north of Golden, British Columbia, infested with *Armillaria ostoyae* (Romagn.) Herink was harvested. Stumps were uprooted on approximately 26 ha of the clearcut in April 1983, with D7 and D8 crawler tractors equipped with brush blades. On scattered portions of this area, stumps not deemed infested were left intact. Uprooted stumps were left on the site (Fig. 1).

The major objectives of the study were to describe the impacts of the stump uprooting operation on soils, on the composition and development of vegetation, and on the growth of planted seedlings. The hypothesis was that disturbance caused by the stump uprooting would have impacts on soil properties that would influence subsequent vegetation development and tree growth. Skidroads located on a portion of the clearcut that was not stumped, were studied concurrently and results published separately (Smith and Wass 1994).

2.0 STUDY AREA

The study area is located near Marl Creek approximately 32 km north of Golden, British Columbia in the Golden Moist Warm variant of the Interior Cedar-Hemlock biogeoclimatic zone (ICHmw1) (Utzig *et al*. 1986; Braumandl and Curran 1992). The major site series identified was Nø. 04 (CwFd-Soopolallie-Douglas maple) (Braumandl and Curran 1992). The average elevation of the site is approximately 1200 m. The general aspect is 230 degrees (SW) with an average slope of 19%.

The original stand was composed of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), lodgepole pine (Pinus contorta var. latifolia Engelm.) and Engelmann spruce (*Picea engelmannii* Parry ex Engelm.). The soils are loams to silt-loams derived from calcareous glacial till and range from shallow to deep over a non-calcareous, phyllitic bedrock. The cutover was broadcast burned after harvesting.

Fig. 1. Uprooted stumps and disturbed ground conditions following the stump uprooting operation.

3.0 METHODS

3.1 Transect Survey

The area of stump uprooting was surveyed in 1984 to determine the extent, degree and type of soil disturbance using a point-transect method (Smith and Wass 1976). Points were spaced 3 m apart along a system of transects located and oriented as recommended by Bloomberg *et al.* (1980). Soil disturbance was classified as deposits or gouges by cause and by three depth classes: <5 cm, 5-25 cm, and >25 cm, or as undisturbed. A total of 612 points were surveyed and described. For general descriptive purposes, vegetative cover was recorded by species and for total cover (see Walmsley *et al.* 1980) at every 10th point (30-m intervals) on mil-acre (4.05-m^2) plots. Similarly, data were gathered from 94 points on transects run in an adjacent unlogged stand.

3.2 Soil Studies

3.2.1 Bulk density. Soil bulk density was measured in 1984 by soil displacement and the volume of excavated holes was estimated with a sand-cone apparatus (Blake 1965). Three samples were taken at each of two depths (0-10 cm and 10-20 cm) in each of three categories (undisturbed, track (the gouge portion), and deposit) in each of four plots, i.e., 12 samples per depth and disturbance category combination. Bulk densities were calculated for the total soil and for the fraction made up of particles less than 2 mm in diameter (the fine fraction).

3.2.2 Penetrability. Penetrability was measured with a U.S. Corps of Engineers Model CN-973 penetrometer equipped with a 1.3-cm^2 cone. Four penetration measurements were made to a depth of 20 cm at each of the bulk density sample sites. For undisturbed soil, the surface organic layer was removed prior to measurements. To reduce variation due to differing soil moisture content, measurements were conducted on the same day.

3.2.3 Particle size. Coarse fragment content of each bulk density sample was determined by sieving and weighing. Texture of the fine fraction of selected samples was determined by the Bouyoucos hydrometer method (McKeague 1978).

3.2.4 Chemistry. The fine fraction of bulk density samples was analyzed for the following characteristics:

1. pH- potentiometrically in 0.01 M $CaCl_2$ (McMullan 1971).
2. organic carbon- LECO induction furnace (McKeague 1978) for samples without carbonates and Walkley-Black (McKeague 1978) for samples reacting to dilute HCl.
3. total nitrogen- automated semi-micro Kjeldahl (McKeague 1978).
4. carbonate equivalence- for samples reacting to dilute HCl, gravimetrically with an HCl-$FeCl_2$ solution (McKeague 1978).

3.2.5 Undisturbed soil profiles. For soil classification purposes, two soil pits located in an uncut stand adjacent to the cutover were described and sampled (Walmsley *et al.* 1980; Agriculture Canada Expert Committee on Soil Survey 1987). Samples taken from the centre of soil horizons were sieved, coarse fragments weighed, textures of the fine fraction determined, and tests were made for total nitrogen, pH, organic carbon and carbonate equivalence. Bulk densities were measured at 10-cm intervals to the bottom of the pits.

Thirty-seven additional pits were dug to a maximum depth of 50 cm in undisturbed soil throughout the area to test for the presence, depth, and strength of carbonate layers using dilute HCl.

3.3 Plantations

3.3.1 Establishment. Three pairs of plots were established, each consisting of one with stump uprooting and one without located as close as possible to one another. One additional plot was established containing a balance of stump uprooted and undisturbed portions. Plots varied from 20×20 m to 30×30 m in size depending on the number of disturbance categories included.

A total of 600 Douglas-fir and 600 lodgepole pine seedlings were planted in the seven plots in the spring of 1985. Fifty trees of each species were planted in each of the categories (undisturbed soil, deposit, or track) found within each plot as follows:

a) three undisturbed plots — undisturbed spots only = 300 trees
b) three plots with stump uprooting — deposits and tracks only = 600 trees
c) one combined plot — undisturbed spots, deposits and tracks = 300 trees.

The two species were planted in alternate rows. Rows were 1 m apart and spacing within rows was subject to the availability and spacial distribution of disturbance categories, but with a minimum spacing of 1 m.

The Douglas-fir seedlings were 2+0 bareroot stock and the lodgepole pine were 1+0 Styroblock 213. Pre-planting measurements of a sample of 50 seedlings of each species showed that Douglas-fir averaged 26 cm and lodgepole pine 16 cm in height. Both species had stem/root weight ratios of 2:1. The seedlings were planted with a planting shovel.

3.3.2 Monitoring and maintenance. Heights and ground-level diameters of all seedlings were measured immediately after planting, after each growing season for 5 years and in the eighth year. Tree condition was assessed at the same time as measurements were made. Dead seedlings were recorded and removed twice per year in the first three growing seasons, and annually thereafter. Trees were thinned to a minimum 2 m spacing after the fifth growing season.

3.3.3 Free carbonates. The presence of free carbonates was tested at the site of each planted tree by applying dilute (10%) HCl to surface mineral soil exposed or otherwise brought to the surface by the planting operation. Reaction was classified as 1 (none), 2 (very weak: few bubbles), 3 (weak: bubbles readily observed), 4 (moderate: bubbles form low foam) and 5 (strong: bubbles form thick foam) (Walmsley *et al.* 1980).

3.3.4 Vegetation. In each of 1985, 1986 and 1987, 60 mil-acre, tree-centred sub-plots were surveyed within the main plots, 20 representing each of deposits, tracks and undisturbed soil. All plants identified in each disturbance category were used to produce dissimilarity percentages (PD) (Pielou 1984). Additionally, plants found in over 40% of plots sampled over a 3-year period were tabulated by disturbance categories.

3.3.5 Plant moisture stress. In late July 1989 (the fifth growing season), six seedlings each of Douglas-fir and lodgepole pine were randomly selected from each of the three disturbance categories from the two most spacially representative paired-plot combinations. Pre-dawn and mid-day plant moisture stress measurements were taken using a pressure chamber (Waring and Cleary 1967). In all, 36 seedlings (12 per disturbance category) of each species were tested.

3.3.6 Soil water content. Gravimetric soil moisture contents were determined for 0-10 and 10-20 cm depths concurrently with the plant moisture stress tests. Samples were taken within a 25-cm radius around the base of each of the 72 seedlings used in the stress tests.

3.3.7 Foliage nutrients and needle weights. In the fall of 1989, samples of current year's foliage were taken for nutrient analyses from the second whorl from the top of six trees of each species per plot, for each of the three disturbance categories. A total of 144 trees were sampled. After drying, 100 needles of each foliage sample were weighed and then returned to the original foliage sample. For chemical analyses, samples were ground and then dried again just before analyses. Total N was analyzed directly on the sample with a LECO FP228 organic nitrogen analyzer and S with a LECO SC132 sulfur analyzer. Active Fe was analyzed from 1 N HCl extract using Atomic Absorption Spectrophotometry (Ballard 1981). The remaining elements were analyzed after digestion using a modified method of Parkinson and Allen (1975) (concentrated sulfuric acid and hydrogen peroxide). Phosphorus was analyzed from the original digest on a Technicon Auto Analyzer using the reduced phospho-molybdate complex. Total Ca, Mg, K, Zn and Mn were analyzed using Inductively Coupled Plasma Spectrometry (ICP).

An internal laboratory standard (Shawnigan Lake Standard Foliage- Douglas-fir) as calibrated against a sample from the National Bureau of Standards (NBS 1575- Pine needles) was used to check the precision of results.

The nutrient status of Douglas-fir and lodgepole pine was evaluated using a computer program developed at the University of British Columbia (Ballard and Carter 1986).

3.4 Data Analysis

Statistical comparisons for ranges of means were conducted using ANOVA followed by the Student-Newman-Keuls' multiple range test (Zar 1974, SAS Institute Inc. 1985). Chi-square tests were applied to differences in survival of trees planted on the different disturbance categories. Pearson correlation coefficients were used to determine significant correlations between depth of gouges and deposits, and seedling height, diameter and volume

4.0 RESULTS

4.1 Undisturbed Soil Profile Characteristics

Soils were Eluviated Eutric Brunisols (Agriculture Canada Expert Committee on Soil Survey 1987) developed on either a calcareous gravelly loam, glacial till deposit with a 20-cm-thick gravelly silt loam, non-calcareous, colluvial capping, or with a thinner till deposit over mainly non-calcareous phyllitic bedrock and a less distinct capping. The thin (4 cm) humus was classified as a hemimor (Klinka *et al.* 1981) with an organic carbon content of 40%, total N content of 1.6%, and a C/N ratio of 25. Sand, silt and clay percentages in the capping averaged 33-38%, 51-53%, and 12-15%, respectively, and, in the till, 35-55%, 34-45% and 10-20%, respectively. Visually estimated volumes of coarse fragments ranged from 5% at the surface to 65% at depth and higher in partially decomposed bedrock. There was a natural, uniform increase in total soil bulk density with depth from an average of 1.07 in the 0-10 cm mineral soil layer to 1.81 in the 60-70 cm layer (Fig. 2 A).

The deeper glacial tills were moderately to strongly calcareous, whereas the shallower tills over bedrock tended to be only weakly to moderately calcareous. Of 37 shallow pits dug in undisturbed soil to determine the presence of carbonate, 22 showed no reaction at an average depth of 46 cm. Reaction in the remaining pits first occurred at an average depth of 28 cm and a strong reaction occurred at 33 cm. In one sampled section of the cutblock, calcareous soil was present immediately below intact humus, but this was the exception. More normally, acidity decreased with depth, with average pH values of 5.6 in the capping and up to 6.7 in the subsoil (Fig. 2 B).

4.2 Ground Surface Conditions

There was no soil disturbance recorded for the unlogged stand (Table 1). Average depth of humus was 4 cm, 88% of which was classified as humified with no rotten wood, 4% as rotten wood, and the

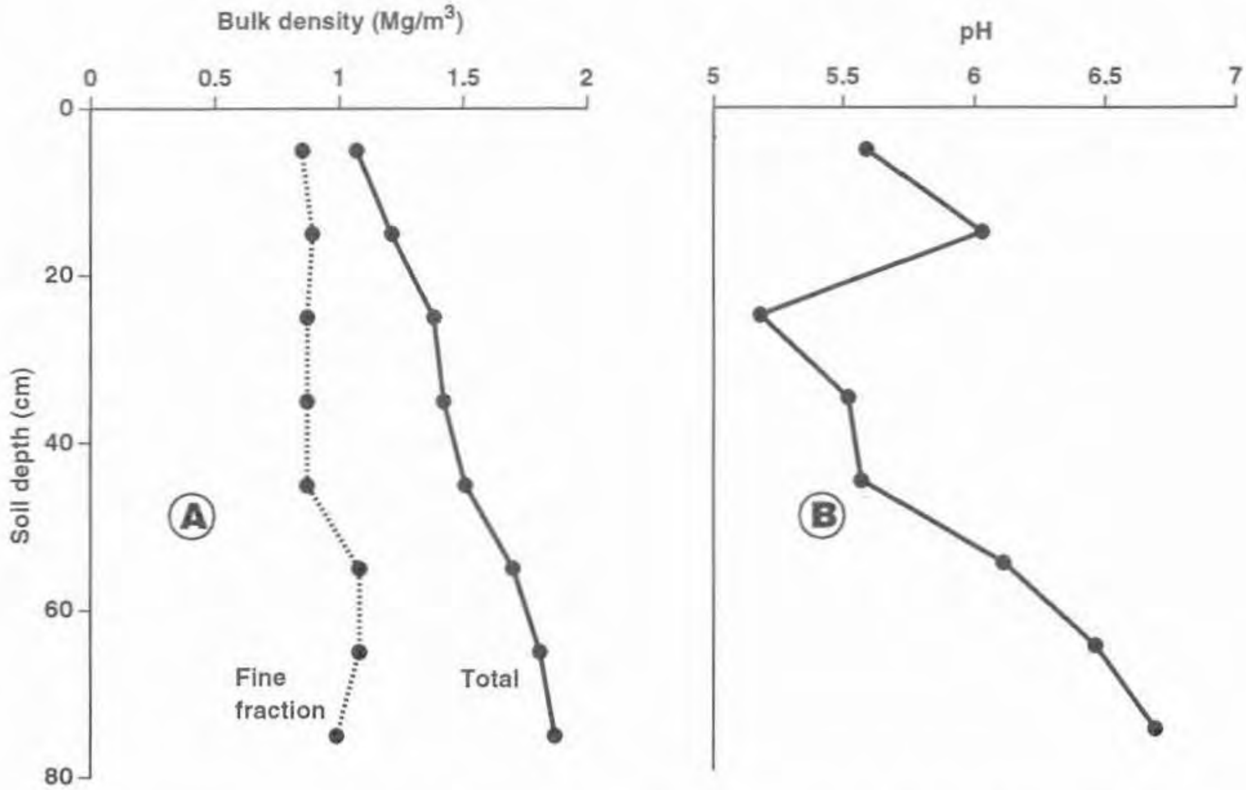

Fig. 2. Average trends with increasing depth of mineral soil in undisturbed soil profiles for: (A) Bulk density; (B) pH ($CaCl_2$).

Table 1. Categories and depths of soil disturbance in the stump uprooted area versus an adjacent unlogged stand

Treatment	Disturbance category*	Depth of soil disturbance**				
		None	S	D	VD	Total
		%				
Uncut	Undisturbed	79	0	0	0	79
	Undisturbed (NL)	17	0	0	0	17
	Undisturbed (TS)	2	0	0	0	2
	Undisturbed (BR)	2	0	0	0	2
		100	0	0	0	100
Stump uprooting	Undisturbed***	13	0	0	0	13
	Undisturbed (NL)	<1	0	0	0	<1
	Undisturbed (ST)	<1	0	0	0	<1
	Undisturbed (LG)	<1	0	0	0	<1
	Undisturbed (SL)	<1	0	0	0	<1
	Stump uprooting					
	- deposits***	0	5	18	15	38
	- gouges***	0	8	20	4	32
	- combined	0	0	1	0	1
	Fireguard	0	1	4	3	8
	Skidroad	0	0	3	1	4
	Other	0	2	<1	0	2
		14	16	47	23	100

* NL= Natural rotting log; TS= Tree stem; BR= Bedrock; ST=Stump; LG= Log; SL= Slash.

** S= Shallow (<5 cm) gouge or deposit; D= Deep (5-25 cm) gouge or deposit; VD= Very deep (>25 cm) gouge or deposit.

*** Soil disturbance categories on which trees were planted.

remainder as mixtures of rotten wood and humified material. Sound woody debris covered 15% and natural, rotting logs covered or were suspended above 20% of the ground surface. There was no reaction when dilute HCl was applied to any of the 94 ground-surface points tested.

Eighty-six percent of the site surface of the stump uprooted area was classified as disturbed soil, of which 72% was disturbed by the stump uprooting operation and 14% mainly by fireguards and skidroads not masked by the stumping operation. Most of the stump uprooting disturbance was in the deep category (5-25 cm). Fifty-eight percent of the stump uprooting disturbance was caused by actual stump removal and 42% from action of the tractor tracks. About 81% of the stump removal disturbance was classified as deposits with the remainder being gouges; 87% of the tractor track disturbance was classified as gouges (tracks) with the remainder as deposits.

Average depth of humus at undisturbed spots was 4 cm, 58% of which was classified as humified with no rotten wood, 17% as rotten wood, 16% as mixtures of rotten wood and humified material and 9% as miscellaneous types. Recent slash covered 21% and natural rotting logs covered 2% of the whole stump uprooting area. Twenty-seven percent of all points tested positively for free carbonates. Reaction increased in frequency and intensity with increasing depth of disturbance (Fig. 3).

4.3 Soil Bulk Density

Total soil bulk density of mineral soil was significantly greater at depths 0-10 cm and 10-20 cm in tracks when compared with deposits or undisturbed soil (Table 2). Fine soil densities were also greater for tracks than the other two categories but with significant differences restricted to the soils in tracks versus those in deposits at the 10-20 cm depth.

4.4 Soil Penetrability

Soils in tracks showed significantly greater resistance to penetration than soils in deposits or in undisturbed conditions, for all depths tested to 20 cm (Fig. 4). Additionally, deposits were more easily penetrated than undisturbed soils, significantly so at depths of 0, 15 and 20 cm. Analysis of these data combined with data from a study of skidroads in the same cutover showed a good correlation between penetrability and bulk density (Smith and Wass 1994).

4.5 Coarse Fragment Content

The relatively low rock content of the upper 10 cm of the undisturbed capping was evident in comparison with tracks and deposits resulting from the stump uprooting operation (Table 3). Differences were not evident at 10-20 cm.

4.6 Soil Chemical Characteristics

Disturbed mineral soil displayed higher organic carbon and higher C:N ratios than undisturbed soil but

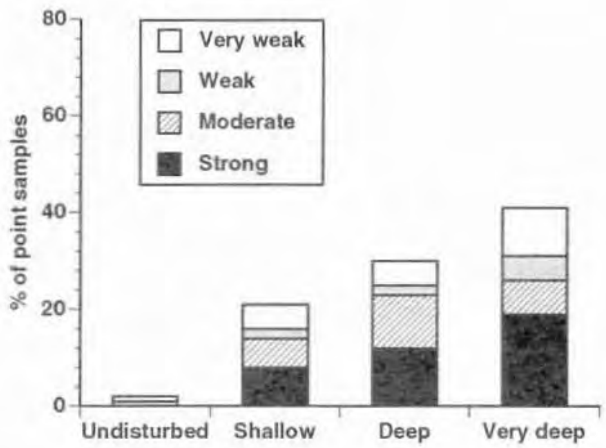

Figure 3. Distribution of levels of soil carbonate as indicated by reaction to HCl for three depths of soil disturbance and undisturbed soil. Shallow<5 cm; Deep = 5-25 cm; Very deep >25 cm. Basis: 609 point-transect samples.

Table 2. Mean bulk densities (Mg/m^3) of total and fine soil fractions for two disturbance categories plus the undisturbed mineral soil at two depths

Disturbance category	Samples	*Depth* — *Total soil* 0-10 cm	*Total soil* 10-20 cm	*Fine soil* 0-10 cm	*Fine soil* 10-20 cm
Undisturbed	12	1.05 b*	1.23 b	0.85 a	0.94 ab
Deposit	12	1.09 b	1.18 b	0.79 a	0.84 b
Track	14	1.32 a	1.47 a	0.93 a	1.14 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.

differences were not significant. The pH levels were markedly lower for the upper 20 cm of undisturbed mineral soil than for disturbed soil, but with statistical significance for the upper 10 cm only (Table 4).

4.7 Carbonate Reaction at Planting Spots

Mineral soil exposed or brought to the surface during the planting operation tested positively for carbonates in only 5% of the cases in undisturbed soil compared with 31 and 35%, respectively, for deposits and tracks (Table 5). About one half of the disturbed soil samples with carbonates reacted moderately or strongly to dilute HCl.

4.8 Tree Seedling Survival

After 5 years, survival of Douglas-fir was significantly greater for seedlings planted in tracks than in either deposits or undisturbed soil (Table 6). Survival of lodgepole pine after 5 years was significantly greater on tracks than on deposits. Lodgepole pine consistently exceeded Douglas-fir in survival rates. Ninety percent of the mortality for Douglas-fir and 89% for lodgepole pine took place during the first two years after planting.

Table 3. Coarse fragment content by weight in bulk density samples

Disturbance category	No. of samples	Coarse fragment content (%)	
		0-10 cm	*10-20 cm*
Undisturbed	12	27 b*	36 a
Deposit	12	39 a	40 a
Track	14	44 a	38 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.

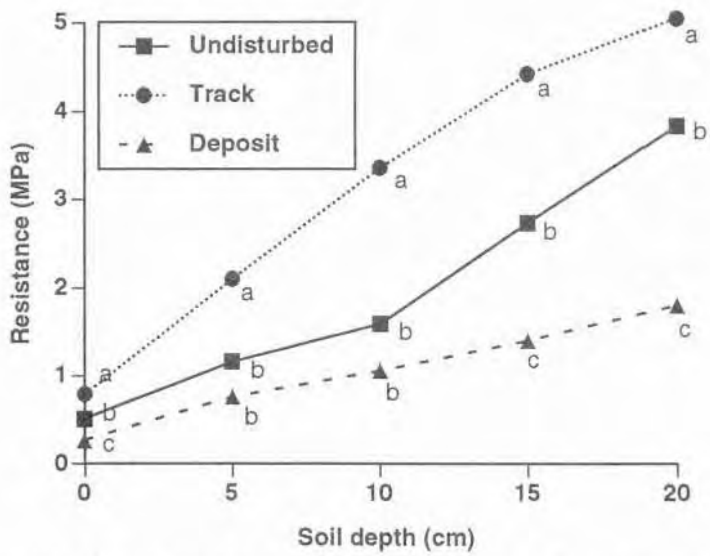

Fig. 4. Resistance (MPa) to penetration of stump uprooting tracks, deposits and undisturbed mineral soil to a depth of 20 cm. Means at the same depth followed by the same letter are not significantly different. Basis: 44 probes for tracks, 52 probes for deposits and 48 probes for undisturbed soil.

Table 4. Chemical characteristics of bulk density samples (Basis= 12 soil samples for undisturbed and deposit and 14 samples for track for each depth)

Disturbance category	Depth (cm)	Organic carbon (%)	Total nitrogen (%)	Carbon/ nitrogen ratio	CO_3 (%)	pH
Undisturbed	0-10	2.0 a*	0.10 a	20.3 a	1.0 a	5.6 b
Deposit	"	2.2 a	0.08 a	25.8 a	2.5 a	6.4 a
Track	"	3.2 a	0.10 a	31.9 a	0.7 a	6.4 a
Undisturbed	10-20	1.4 a	0.08 a	18.8 a	2.5 a	5.9 a
Deposit	"	1.9 a	0.08 a	21.9 a	1.5 a	6.2 a
Track	"	1.7 a	0.07 a	20.6 a	5.2 a	6.4 a

* Means within columns and depth classes followed by the same letter are not significantly different at the 0.05 level.

Table 5. Carbonate reaction at planting spots

Disturbance category	No. of spots tested	Level of carbonate reaction (%)				
		None	V. weak	Weak	Moderate	Strong
Undisturbed	410	95	2	2	<1	<1
Deposit	406	69	8	7	8	8
Track	405	64	11	8	9	8

Table 6. Survival rates (%) of Douglas-fir and lodgepole pine seedlings planted on two stump uprooting disturbance categories and on undisturbed ground after five growing seasons (Basis= 200 trees of each species planted in each disturbance category)

Disturbance category	Douglas-fir	Lodgepole pine
Undisturbed	56 b*	90 ab
Deposit	61 b	82 b
Track	86 a	95 a

* Means within columns and species followed by the same letter are not significantly different at the 0.05 level (Chi-square test).

4.9 Tree Seedling Growth

Mean heights, diameters, and volumes of Douglas-fir and lodgepole pine seedlings, based on measurements made immediately after planting in May 1985 were not significantly different among disturbance classes.

After 5 years, height, diameter and volume of Douglas-fir were all lower for seedlings planted in tracks than for those planted in deposits or in undisturbed ground, but differences were not significant (Table 7). After 8 years, mean height and diameter was significantly greater for Douglas-fir seedlings planted in undisturbed soil than in tracks.

Greatest height, diameter and volume growth of lodgepole pine occurred with undisturbed soil and the least with tracks (Table 8). After 5 years, the height of seedlings planted in tracks was significantly less than for those in either deposits or undisturbed soil. The average diameter of lodgepole pine seedlings growing in tracks was significantly less than for those in undisturbed soil. Although the average volume of pine in tracks was 16% less than the average in

Table 7. Mean heights, ground-level diameters and volumes of Douglas-fir seedlings for two stump uprooting disturbance categories and undisturbed ground after five and eight growing seasons

Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
After 5 growing seasons				
Undisturbed	103	65.6 a*	15.2 a	43.3 a
Deposit	113	65.5 a	15.0 a	46.5 a
Track	159	60.8 a	14.5 a	41.9 a
After 8 growing seasons				
Undisturbed	46	134 a	35 a	470 a
Deposit	52	136 a	34 a	506 a
Track	60	116 b	30 b	354 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.

Table 8. Mean heights, ground level diameters and volumes of lodgepole pine seedlings for two stump uprooting disturbance categories and undisturbed ground after five and eight growing seasons

Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
After 5 growing seasons				
Undisturbed	166	96.4 a*	21.3 a	130.1 a
Deposit	154	94.0 a	20.3 ab	126.7 a
Track	176	87.7 b	19.8 b	109.9 a
After 8 growing seasons				
Undisturbed	52	206 a	48 a	1369 a
Deposit	57	196 ab	47 a	1304 a
Track	60	181 b	43 a	1050 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.

undisturbed soil, this difference was not significant. After 8 years, the height of lodgepole pine growing in undisturbed soil was significantly greater than in tracks.

Douglas-fir had greater average height for tracks and deposits than for undisturbed soil for the first year, but growth in tracks slowed considerably in subsequent years relative to growth in undisturbed soil, reaching a 14% reduction by the eighth year (Fig. 5). Douglas-fir volumes for tracks were initially slower to follow this downward trend but by year 8 were 25% less than for the same species planted in undisturbed soil (Fig. 6). Height and volume growth of Douglas-fir in deposits remained consistently close to growth in undisturbed soil over the 8 years.

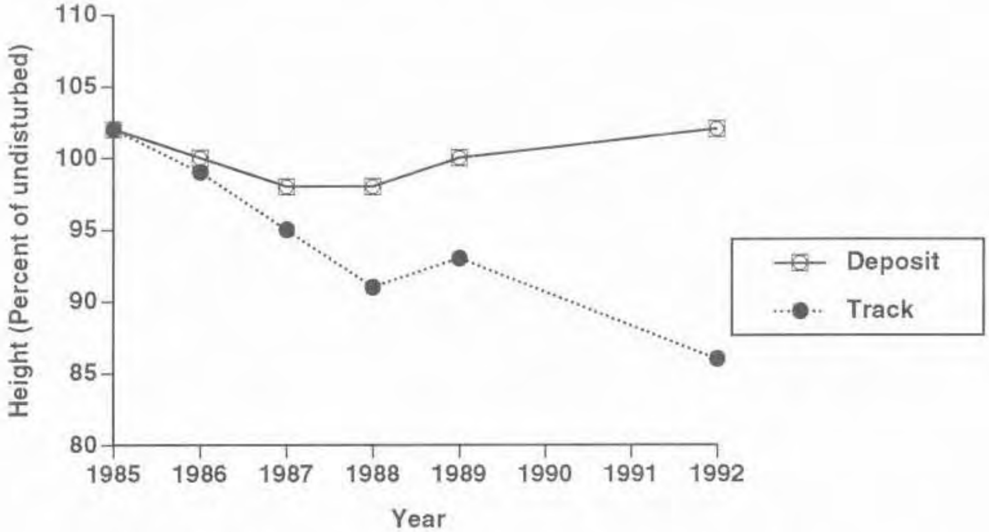

Fig. 5. Mean height of Douglas-fir growing on soil disturbed by stump uprooting as a percentage of its mean height on undisturbed soil.

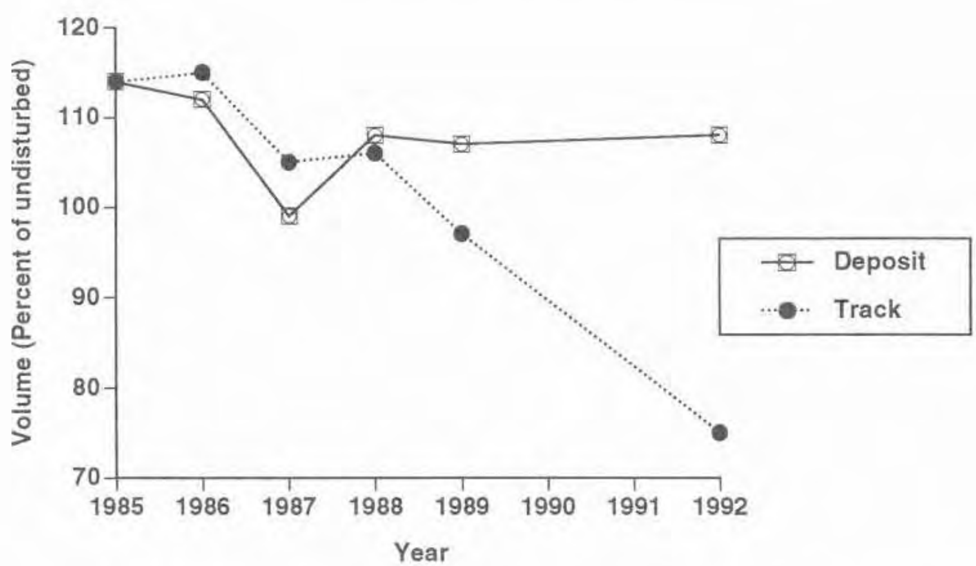

Fig. 6. Mean volume of Douglas-fir growing on soil disturbed by stump uprooting as a percentage of its mean volume on undisturbed soil.

The average height and volume of lodgepole pine growing in tracks dropped below that for undisturbed soil after the first year and subsequently stayed well below, reaching reductions of 12 and 23%, respectively, by the eighth year (Fig. 7,8). Height and volume growth of lodgepole pine in deposits was consistently about 5% less than its growth in undisturbed soil over the 8 years.

Growth of both species was generally less when planted in spots for which the surface mineral soil reacted moderately or strongly to dilute HCl (Fig. 9,10). Statistically significant differences for Douglas-

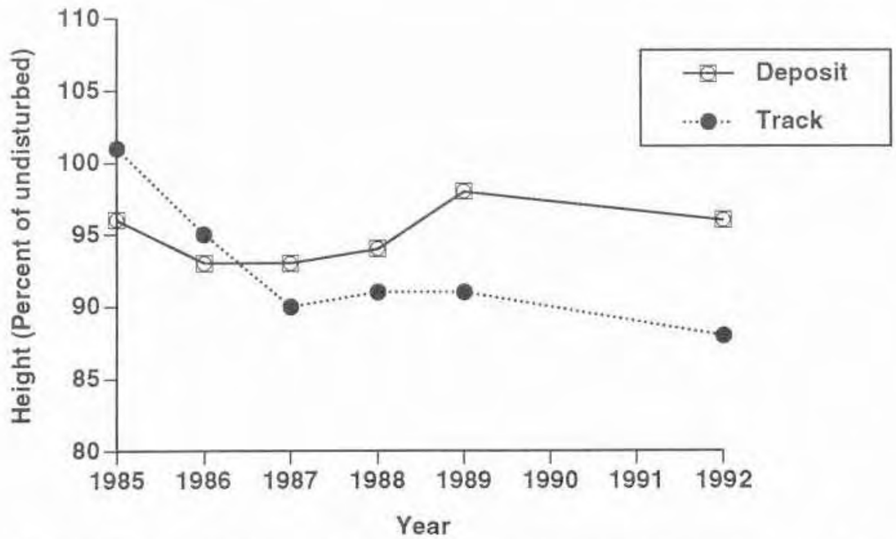

Fig. 7. Mean height of lodgepole pine growing on soil disturbed by stump uprooting as a percentage of its mean height on undisturbed soil.

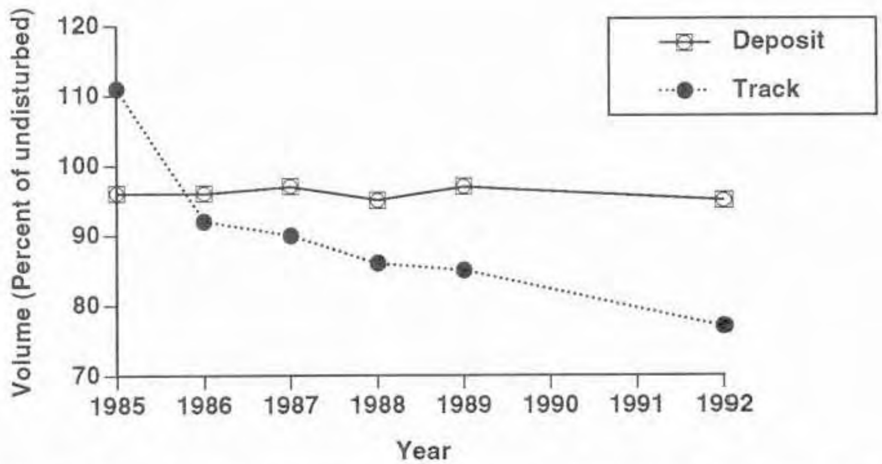

Fig. 8. Mean volume of lodgepole pine growing on soil disturbed by stump uprooting as a percentage of its mean volume on undisturbed soil.

fir after 5 years were restricted to greater height growth at planting spots which had weak, very weak or no reaction to HCl than at spots with a moderate reaction. For lodgepole pine, height after 5 years was significantly less at spots with a strong reaction versus those with a lesser reaction, and volume growth was significantly less at spots with a strong reaction versus those with a very weak reaction.

There were highly significant correlations (Pearson's) between the depth of the track below the original soil surface and height, diameter and volume of both Douglas-fir and lodgepole pine, indicating that the deeper the track the slower the growth rate. Correlation coefficients ranged from 0.29 to 0.34. Similar correlations for depth of deposit did not exist or were very weak.

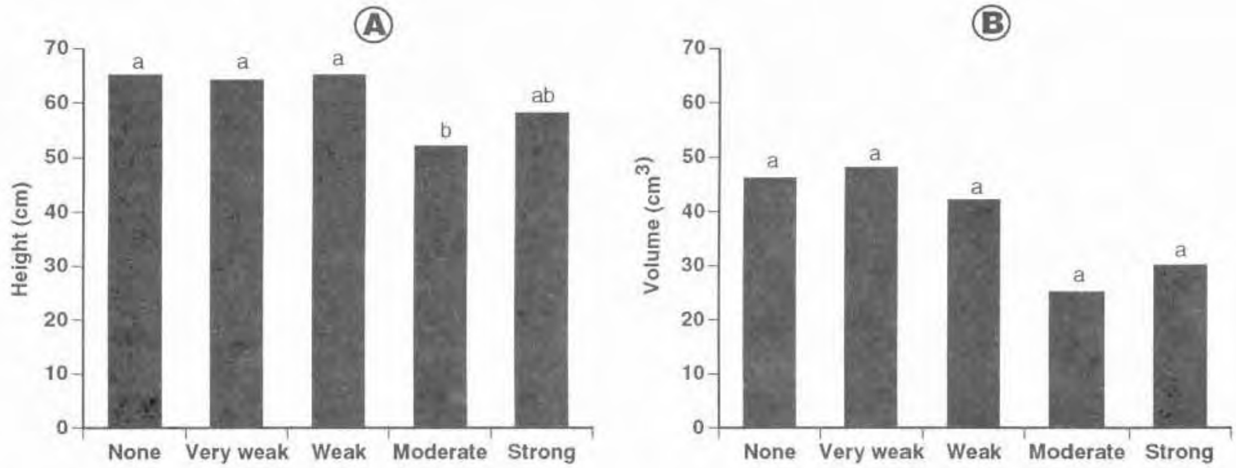

Fig. 9. Height (A) and volume (B) growth after 5 years of Douglas-fir by dilute HCl reaction classes. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level.

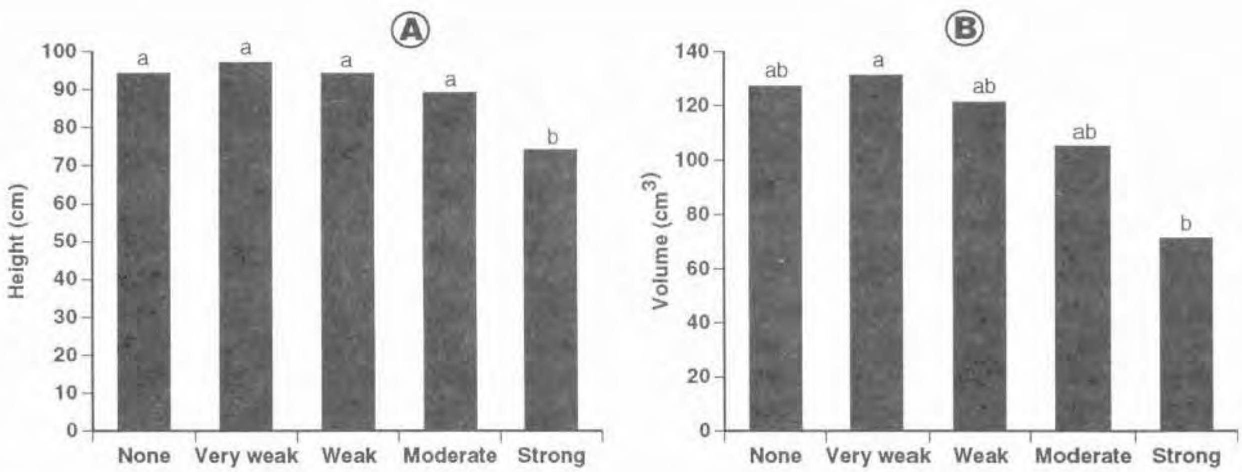

Fig. 10. Height (A) and volume (B) growth after 5 years of lodgepole pine by dilute HCl reaction classes. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level.

4.10 Plant Moisture Stress

Plant moisture stress was generally higher for seedlings growing in deposits than for those growing in the undisturbed soil or in tracks (Table 9). However, the only significant difference was a greater pre-dawn stress for lodgepole pine planted in deposits than those planted in undisturbed soil. These plant moisture stress data and data on gravimetric soil water taken concurrently have been included for correlation analyses in the companion paper dealing with skidroads (Smith and Wass 1994).

4.11 Foliage Weights and Nutrients

The weights per 100 needles did not differ significantly for either Douglas-fir (0.32 g for deposits to 0.36 g for undisturbed soil) or lodgepole pine (2.95 g for tracks to 3.18 g for deposits) among disturbance categories.

There were few significant differences in foliage nutrients among the disturbance classes (Table 10). However, calcium concentration tended to be higher for trees planted in disturbed compared with undisturbed soil, significantly so for Douglas-fir planted in deposits versus undisturbed soil. Manganese and K concentration for Douglas-fir growing in deposits was significantly greater than for foliage from trees planted in tracks or undisturbed soil.

A diagnosis of nutrient deficiency (Ballard and Carter 1986), indicated a severe deficiency in N for Douglas-fir growing in undisturbed soil but only a slight to moderate deficiency in N for Douglas-fir in deposits and tracks. Douglas-fir foliage had a slight to moderate possible deficiency in Mg and was possibly deficient in S when growing in tracks and undisturbed soil.

Lodgepole pine foliage generally tended to be more deficient in nutrients than Douglas-fir. Its foliage was slightly to moderately deficient in N, moderately deficient in P and possibly slightly to moderately deficient in Mg for all three disturbance categories. Additionally, likely deficiencies in active Fe were indicated for seedlings growing in tracks and undisturbed soil. Lodgepole pine seedlings growing in tracks had a slight possible deficiency in K and trees in undisturbed soil had a deficiency or potential nitrogen induced deficiency in S.

4.12 Vegetation

By 1985, 2 years after the stumping operation, total vegetative cover on undisturbed soil was over 2.5 times that on tracks and a little less than twice that on deposits (Fig. 11). In the following two years, cover on tracks and more markedly on deposits increased, whereas cover decreased on undisturbed soil.

In comparisons among disturbance categories, vegetation composition and cover were most dissimilar between tracks and unlogged ground and least dissimilar between tracks and deposits (Table 11).

Table 9. Mean pre-dawn and mid-day moisture stress values (MPa) for Douglas-fir and lodgepole pine trees on July 27-29, 1989, for two stump uprooting disturbance categories and undisturbed ground*

Disturbance category	No. of trees	Douglas-fir		Lodgepole pine	
		Pre-dawn	Mid-day	Pre-dawn	Mid-day
Undisturbed	12	0.44 a**	1.78 a	0.46 b	1.47 a
Deposit	12	0.50 a	1.91 a	0.55 a	1.67 a
Track	12	0.41 a	1.79 a	0.51 ab	1.61 a

* Weather partly cloudy on July 27, some thundershowers on July 28 with wetting of the soil down to 2 cm and sunny and warm on July 29. Temperatures ranged from 12°C overnight to 27°C during the day and humidities from 35% during the day to 93% at night.

** Means within columns followed by the same letter are not significantly different at the 0.05 level.

Table 10. Mean concentration of nutrients in foliage of Douglas-fir and lodgepole pine seedlings for two stump uprooting categories and undisturbed soil (Basis= 12 trees for each species and disturbance category)

	Douglas-fir			Lodgepole pine		
Nutrient	Undisturbed	Deposit	Track	Undisturbed	Deposit	Track
	%					
N	1.27 a*	1.37 a	1.31 a	1.23 a	1.32 a	1.37 a
P	0.168 a	0.166 a	0.170 a	0.113 a	0.111 a	0.113 a
K	0.76 b	0.85 a	0.76 b	0.50 a	0.54 a	0.49 a
Ca	0.37 b	0.45 a	0.43 ab	0.26 a	0.28 a	0.29 a
Mg	0.092 a	0.103 a	0.097 a	0.077 a	0.084 a	0.084 a
S	0.137 a	0.145 a	0.130 a	0.120 a	0.130 a	0.134 a
	ppm					
Zn	34.4 a	46.2 a	40.8 a	47.9 a	54.5 a	50.5 a
Mn	114.8 b	197.0 a	129.5 b	105.1 a	122.3 a	103.1 a
Fe (active)	37.8 a	42.6 a	38.5 a	28.5 a	35.0 a	30.0 a

* Means within species and rows followed by the same letter are not significantly different at the 0.05 level.

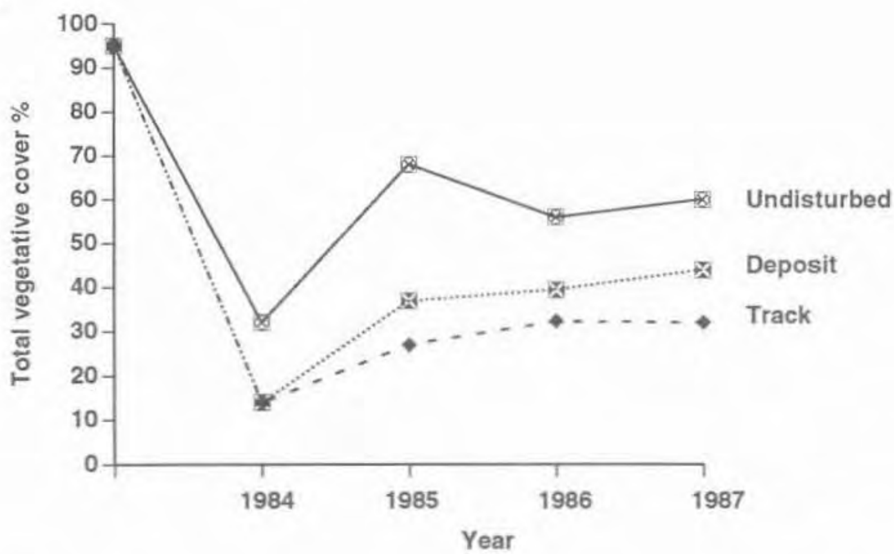

Fig. 11. Trends in total vegetative cover following clearcut logging and stump uprooting for undisturbed soil and for two stump uprooting disturbance categories. Initial cover (95%) comes from an adjacent unlogged stand.

Acer glabrum Torr., *Shepherdia canadensis* Nutt., *Mahonia aquifolium* Nutt. and *Pleurozium schrebiri* (Brid.) Mitt. occurred frequently only in the unlogged stand (Table 12). *Populus tremuloides* Michx., *Ceanothus sanguineus* Pursh, and *Osmorhiza chilensis* Hook. & Arnott were found frequently only on undisturbed soil of the cutover. Although more abundant in the unlogged stand and on undisturbed soil of the cutover, *Disporum trachycarpum* (Wats.) Benth. & Hook. was also a frequent colonizer of deposits but not of tracks. *Aralia nudicaulis* L. was frequent on undisturbed soil and deposits in the cutover. *Spiraea betulifolia* Pall. and *Paxistima myrsinites* (Pursh.) Raf. were frequent in the unlogged stand and in all categories of the cutover. *Rubus parviflorus* Nutt., *R. idaeus* L., *Epilobium angustifolium* L. and *E. minutum* Lindley ex W.J. Hook. were not present in over 40% of plots in the unlogged stand but were frequent in all three cutover categories. *Taraxicum* sp Wiggers, *Aster conspicuus* Lindley in Hook. and *Epilobium watsonii* Barbey were frequent only on tracks.

5.0 DISCUSSION AND CONCLUSIONS

The stump uprooting operation disturbed 72% of the ground in the cutblock, 42% from stump removal and 30% from tractor tracks. This compares with 45% of ground surface disturbed in the same cutblock as a result of log skidding only (Smith and Wass 1994). The increased disturbance caused by the stump uprooting was mainly in the shallow and deep disturbance categories, i.e., gouges (mainly tracks) and deposits less than 25 cm deep. Higher levels (100% cover) of soil disturbance were previously reported in two cutovers in which the uprooted stumps were windrowed or piled (Smith and Wass 1991). In an operation more similar to the one in this study (Smith and Wass 1989), disturbance from stump uprooting was 70%, 38% from stump removal and 32% from tractor tracks. It is evident that stump uprooting with a bulldozer even when stumps are left *in situ* causes a high frequency of soil disturbance. However this disturbance is not on average as deep nor are the number of tractor passes as many as those resulting from the construction and use of skidroads. Consequently, changes in soil characteristics which may be detrimental to site productivity tend to be less marked with stump uprooting. Average total soil bulk densities for tracks associated with stump uprooting were 23% higher than for the same depth (0-20 cm) in undisturbed mineral soil as compared with an increase of 52% and 44% for inner and outer skidroad tracks, respectively, over undisturbed soil in the same cutover (Smith and Wass 1994). Studies of the impacts of stump uprooting in two other sites (Smith and Wass 1991) showed increased bulk densities in tracks averaging 26% and 16%. Increased bulk densities on skidroad running surfaces for five sites (Smith and Wass 1985) ranged from 20% for the middle of the running surface to 44% for the inner track.

Average penetrability in the top 20 cm of tracks associated with stump uprooting in this study was 68% higher than in undisturbed soil to the same depth, but not much less than the average 74% increase for inner and outer skidroad tracks in the same cutblock (Smith and Wass 1994). Studies of impacts from stump uprooting operations on two other sites (Smith and Wass 1994) showed increased resistance to penetration averaging 129% and 80%, whereas increased resistances for skidroad running surfaces for five sites (Smith and Wass 1985) averaged 218% (92-315%).

Based on our own and other similar studies published for interior British Columbia (Table 13), average increase in bulk density was 21% for tracks

Table 11. Average dissimilarity indices (%) for plant species for three years (1985-87) for unlogged stand and stumping disturbance category comparisons

	Unlogged	Undisturbed	Deposit	Track
Unlogged	0	78	78	85
Undisturbed		0	41	50
Deposit			0	34
Track				0

caused by stump uprooting operations, 44% for skidroads and skid trails and 92% for landings, indicating a relatively low detrimental effect of stump uprooting, an intermediate effect of skidroads and skid trails, and a high effect of landings. For those studies in which it was measured, resistance to penetration increased an average of 92% for tracks in stump uprooting operations and 161% for skidroad and skid trail running surfaces. Studies in seedling root development in the same cutover (E.F. Wass and R.B. Smith, Impacts of soil disturbance on root systems of Douglas-fir and lodgepole pine seedlings. Manuscript in preparation.) also indicated that stump uprooting tracks had a lesser impact on number, volume and spatial distribution of seedling roots than the inner track of skidroads.

The lower impact of stump uprooting operations on soil is reflected in tree growth rates. Average volumes after 8 years were 25% lower for Douglas-fir seedlings and 23% lower for lodgepole pine growing on tracks caused during stump uprooting than when these trees were growing on undisturbed ground. On inner and outer skidroad tracks in the same cutblock, comparable reductions after 8 years were 38 and 8%, respectively, for Douglas-fir and 49 and 26%, respectively, for lodgepole pine. However, overall productivity losses are influenced by extent as well as degree of soil disturbance. For this area, 72% of the ground was disturbed by the stump uprooting activities. This was made up of deposits (38%) and gouges (mainly tracks) (34%). Estimated losses in productivity resulting from stump uprooting, prorated over the affected portion of the cutover, are 4% based on height and 5% on volume for Douglas-fir, and 6% based on height and 10% on volume for lodgepole pine. For both species, these prorated losses are slightly greater than estimated for the same species for the ground skidded portion of the cutover (Smith and Wass 1994). The lower prorated reduction for Douglas-fir results from its greater volume growth on deposits than on undisturbed soil. Deposits created by stumping operations tend to be looser and less

Table 12. Average frequency (F) in % and cover (C) in % of plants for 3 years (1985-87) present in more than 40% of sampled plots for the unlogged stand and for three stump uprooting disturbance categories

	Unlogged		Undisturbed		Deposit		Track	
	F	C	F	C	F	C	F	C
Shepherdia canadensis	74	11	-	-	-	-	-	-
Pleurozium schrebiri	53	2	-	-	-	-	-	-
Acer glabrum	42	7	-	-	-	-	-	-
Mahonia aquifolium	42	1	-	-	-	-	-	-
Populus tremuloides	-	-	52	6	-	-	-	-
Ceanothus sanguineus	-	-	60	2	-	-	-	-
Osmorhiza chilensis	-	-	53	1	-	-	-	-
Disporum trachycarpum	95	8	63	5	45	1	-	-
Aralia nudicaulis	-	-	67	2	48	3	-	-
Spiraea betulifolia	74	5	97	15	93	8	77	4
Paxistima myrsinites	95	21	88	3	85	1	95	1
Rubus parviflorus	-	-	92	10	73	5	68	6
Epilobium angustifolium	-	-	82	5	95	8	88	4
Rubus idaeus	-	-	72	4	57	5	63	5
Epilobium minutum	-	-	75	1	80	1	90	2
Taraxacum sp	-	-	-	-	-	-	62	1
Aster conspicuus	-	-	-	-	-	-	43	1
Epilobium watsonii	-	-	-	-	-	-	50	1

resistant to penetration than undisturbed soils and even more markedly so when compared with tracks. Although the lower soil density of deposits contributes to reasonable growth rates it also results in relatively low survival of planted seedlings.

Reduction of natural rotting log cover from 20% in uncut stands to only 2%, and an increase in humus with an appreciable rotten wood component from 12% in uncut stands to 33% reflect a greater redistribution of organic matter than indicated for the ground skidding operation alone on the same cutover (Smith and Wass 1994).

The lower impact on soil caused by the stump uprooting operation relative to skidroad construction and use is seen also in subsequent development of vegetation. Dissimilarity indices for comparisons of vegetation composition and cover ranged from 83 to 86% between inner skidroad track and undisturbed soil and 57 to 58% between outer track and undisturbed soil (Smith and Wass 1994) as compared with 50% between stump uprooting tracks and undisturbed soil. However, as with impacts on productivity, those stump uprooting impacts on surface soil and vegetation normally extend over a greater proportion of a cutblock than those resulting from skidding operations alone. Stump uprooting disturbance can be reduced by limiting stump removal to those stumps which have been identified as being infected with root disease.

Table 13. A comparison of increased bulk density and resistance to penetration for stump uprooting tracks, skidroad tracks and landings from this and similar studies in interior British Columbia

Disturbance category	Change in comparison to undisturbed control (%): Bulk density	Change in comparison to undisturbed control (%): Resistance	Source
Stump uprooting track	+23	+68	This paper
Stump uprooting track	+25	+129	Smith and Wass 1991*
Stump uprooting track	+16	+80	Smith and Wass 1991*
Inner skid trail	+58	-	McLeod 1988**
Mid skid trail	+50	-	McLeod 1988**
Outer skid trail	+67	-	McLeod 1988**
Inner skidroad track	+44	+259	Smith and Wass 1985***
Mid-skidroad	+20	+178	Smith and Wass 1985***
Outer skidroad track	+24	+218	Smith and Wass 1985***
Inner skidroad track	+52	+62	Smith and Wass 1994
Outer skidroad track	+40	+86	Smith and Wass 1994
Summer landing	+71	-	Carr 1987
Winter landing	+51	-	Carr 1987
Landing	+91	-	McLeod 1988**

* Two study areas
** Averaged for three study sites
*** Averaged for five study sites

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