



# Impacts of skidroads 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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## Abstract

A plantation consisting of three plots with 160 seedlings each of Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta* var. *latifolia*) was established in a cutover north of Golden, British Columbia, in the Interior Cedar-Hemlock biogeoclimatic zone. To determine the impact of contour-built skidroads on survival and subsequent growth of planted seedlings, plots straddled selected segments of the skidroads. Seedlings were planted in four disturbance categories on the skidroads and in undisturbed soil above and below the skidroads. Soil characteristics were measured initially on the skidroads and in the undisturbed soil adjacent to the skidroads and tree growth was monitored for eight growing seasons after planting. Foliage was sampled for nutrient content at the end of the fifth year.

The greatest adverse impacts on the soil were found in the inner track, i.e., the portion of the skidroads lying next to the cutbank. Here, the top 20 cm of mineral soil was on average 52% denser and 62% more resistant to penetration than the equivalent depth of undisturbed mineral soil. Soils in the outer track were also seriously degraded whereas the soils in the berm were not markedly different from the undisturbed situation in terms of density and penetrability. Disturbance exposed subsoil with inherently higher levels of free carbonates and a pH range of 6.3-7.0 compared with an average of 5.3 for the upper portion of undisturbed soil.

Survival of Douglas-fir seedlings was significantly greater on the skidroad surface than on sidecast or undisturbed soil. However, growth of both Douglas-fir and lodgepole pine was reduced on skidroads, particularly in the inner track; reductions 5 years after planting amounted to 33% in height and 53% in volume for Douglas-fir and 32% and 48%, respectively, for lodgepole pine. After 8 years reductions were generally less, amounting to 25% in height and 38% in volume for Douglas-fir and 26% and 49%, respectively, for lodgepole pine. Growth of seedlings planted in the sidecast and berm was not significantly different than in undisturbed soil. The distinct character of the inner track was evident also by a relatively slow development of vegetation and by a composition of plant species dissimilar from that found on other parts of the skidroad or on undisturbed ground.

Correlations are made among soil and seedling growth characteristics to explain some of the results and to guide further research.

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## Résumé

Une plantation constituée de 3 lots comptant chacun 160 semis de douglas taxifolié (*Pseudotsuga menziesii*) et de pin tordu (*Pinus contorta* var. *latifolia*) a été mise sur pied dans une coupe au nord de Golden, en Colombie-Britannique, dans la zone biogéoclimatique thuya-pruche de l'Intérieur. Afin de déterminer les répercussions des chemins de débardage longeant les pentes sur la survie et la croissance subséquente des semis plantés, on a délimité des lots chevauchant des segments sélectionnés de chemins de débardage. Les semis ont été plantés dans 4 catégories de sol dérangé sur les chemins de débardage, ainsi que dans des sols non dérangés en haut et en bas de ces chemins. Les caractéristiques des sols ont été mesurées au début de l'étude sur les chemins et dans le sol non dérangé adjacent à ceux-ci, et la croissance des arbres a été surveillée au cours de 8 saisons de croissance après la plantation. On a échantillonné le feuillage pour déterminer la teneur en nutriments à la fin de la cinquième année.

Les incidences néfastes les plus importantes pour le sol ont été observées dans la trace interne, c'est-à-dire la portion du chemin de débardage adjacente au flanc de la colline. Dans celle-ci, la portion supérieure de 20 cm de sol minéral était en moyenne 52 % plus dense et 62 % plus résistante à la pénétration que le sol minéral non dérangé situé à une profondeur équivalente. Le sol de la trace extérieure était également sérieusement dégradé, alors que celui des banquettes n'était pas très différent du sol non dérangé pour ce qui est de la densité et de la pénétrabilité. Le sous-sol exposé par les travaux présentait des teneurs nettement plus élevées en carbonates libres et une plage de pH de 6,3 à 7,0, par rapport à une valeur moyenne de 5,3 dans la portion supérieure de sol non dérangé.

Le taux de survie des semis de douglas taxifolié était significativement plus élevé à la surface du chemin de débardage que sur les côtés ou sur le sol non dérangé. Toutefois, la croissance des semis de douglas taxifolié et de pin tordu était plus faible sur le chemin de débardage, et plus particulièrement dans la trace intérieure; 5 ans après la plantation, la hauteur était inférieure de 33 % et le volume, de 53 % dans le cas du douglas taxifolié, et on notait des diminutions de 32 et de 48 %, respectivement, pour le pin tordu. Après 8 ans, les diminutions observées étaient généralement inférieures, soit de 25 % pour la hauteur et de 38 % pour le volume dans le cas du douglas taxifolié, et de 26 et de 49 %, respectivement, pour le pin tordu. La croissance des semis plantés sur les côtés et les banquettes ne présentait pas de différence significative par rapport à celle observée pour le sol non dérangé. Le caractère distinctif de la trace inférieure était également évident à cause de la lenteur du développement de la végétation, ainsi que de la composition en espèces qui la caractérisait, différente de celle observée sur les autres parties du chemin de débardage ou sur le sol non dérangé.

On a fait des corrélations entre les sols et les caractéristiques de croissance des semis pour expliquer certains des résultats et pour guider les recherches ultérieures.

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## 1.0 INTRODUCTION

Calcareous soils, i.e., soils with free carbonates, have long been considered a poor growth substrate for many plant species (Thorne and Seatz 1955). Smith (1988) summarized the difficulties in establishing and maintaining a conifer nursery on a calcareous soil in the East Kootenay region of British Columbia. The nursery was finally abandoned in 1967. Utzig and Herring (1975) considered displacement of non-calcareous topsoil and exposure of deeper calcareous horizons as detrimental to the growth of conifer regeneration. Retrospective comparisons of tree growth on disturbed and undisturbed calcareous soil have supported this last contention (Smith and Wass 1979, 1980; Thompson 1990). Results from these latter studies represented a long time period without requiring long-term monitoring. However, these studies lacked basic environmental data, particularly conditions existing at the early stages of stand development. For this reason the earlier studies were supplemented with the establishment of tree plantations on disturbed soil. These plantations not only allowed environmental monitoring but also control of tree species, stocking levels and vegetative competition.

An opportunity to study the changes in soil characteristics and in site productivity resulting from mechanical disturbance of a calcareous soil arose in 1982 when a root-rot infested stand north of Golden, British Columbia was harvested. Stumps were uprooted on more than half of the cutover. A portion of the lower slope of the clearcut where stumps were not uprooted contained several skidroads built on the contour, thus allowing independent examination of the effects of the skidroads. The portion with stump uprooting has also been studied and these results are reported separately (Smith and Wass 1994). However, where deemed appropriate and to provide a more substantial data base, some correlation analyses in this paper included data from both the stump uprooting and skidroad treatments.

The major objectives of this study are to describe the impacts of the constructed skidroads on soils, on vegetation composition and development and on the growth of planted seedlings. The hypothesis is that the impacts of the construction and use of skidroads on soil properties, vegetation development and seedling growth would vary with the type and degree of the soil disturbance.

## 2.0 STUDY AREA

### 2.1 Ecology and Soils

The cutblock (FL A17645, Blk. 14, CP 20) is located near Marl Creek approximately 32 km north of Golden in southeastern British Columbia. It lies 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 No. 4: CwFd-Soopolallie-Douglas maple (Braumandl and Curran 1992). The average elevation of the site is 1070 m, the aspect generally southwest and the average slope 27%. The original stand was composed primarily of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) with lesser amounts of Engelmann spruce (*Picea engelmannii* Parry ex Engelm.).

The soil, a loam to silt-loam Orthic Eutric Brunisol (Agriculture Canada Expert Committee on Soil Survey 1987), was derived from deep (over 100 cm) calcareous glacial till. The study area was broadcast burned after logging.

### 2.2 Skidroads

The skidroads were oriented along the contour. Based on nine cross-sections, cutbanks averaged 0.8 m in depth. The horizontal distance from the top of the cutbank to the bottom of the sidecast averaged 6.8 m, composed of a cutbank (1.2 m), running surface (3.0 m), berm (1.0 m) and sidecast (1.6 m).

## 3.0 METHODS

### 3.1 Transect Survey

The whole cutblock was surveyed to determine the extent, degree and type of soil disturbance using a point-transect method. Points were spaced 3 m apart (Smith and Wass 1976) along a system of transects located and orientated as recommended by Bloomberg et al. (1980). At every 10th point (30 m), vegetation cover was recorded by species and as a total (see Walmsley et al. 1980). Data are reported only from the portion of the cutblock encompassing the skidroad study area and, for comparison, from an unlogged area bordering the cutblock.

## 3.2 Soil Studies

**3.2.1 Bulk density.** Soil bulk density was measured by soil displacement and the volume of excavated holes was estimated with a sand-cone apparatus (Blake 1965). Two samples were taken at each of two depths (0-10 cm and 10-20 cm) in each of three disturbance categories in each of three plots. Disturbance categories were the inner and outer skidroad tracks (running surface) and the berm. Three samples were taken at each depth in undisturbed mineral soil in an adjacent plot. Bulk densities were calculated for the total soil and for the fine fraction, i.e. particles less than 2 mm in diameter.

**3.2.2 Penetrability.** Penetrability was measured with a U.S. Corps of Engineers Model CN-973 penetrometer equipped with a 1.3 cm<sup>2</sup> cone. Four probes were made to a 20 cm depth at each of the two bulk density sites situated in the skidroad inner track, outer track and berm in each of the three plots. After removing humus, four probes were made at each of the three bulk density sites in undisturbed mineral soil in the adjacent plot. To reduce variation due to differing moisture content, all 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<sub>2</sub> (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<sub>2</sub> solution (McKeague 1978).

**3.2.5 Soil profiles.** One soil pit, located at the bottom of the cutover, was described, sampled and classified (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 made for total nitrogen, pH, organic carbon and carbonate equivalence. Additionally, 11 shallower pits were dug throughout the study area solely for carbonate testing with dilute HCl.

## 3.3 Plantations

**3.3.1 Layout.** Three plots approximately 20 x 40 m were established, each straddling discrete skidroad sections and including undisturbed ground above and below the skidroads. One hundred and sixty seedlings each of Douglas-fir and lodgepole pine were planted in May 1985 in each of the three plots for a total of 960 trees (Fig. 1). Rows with alternating species were oriented perpendicular to the skidroads at a 1 m spacing. Within the rows, seedlings were planted in pre-marked spots representing the **upper undisturbed soil, inner track, outer track, berm, sidecast** and the **lower undisturbed soil** (Fig. 2).



Fig. 1. Staked skidroad and adjacent undisturbed soil in preparation for tree planting.

Spacing within rows varied but was not less than 1 m. Two trees were planted per row in the upper and lower undisturbed soil. However, when extensive sidecast prevented establishing two trees in the lower undisturbed soil, up to four were planted above. One tree per row was planted in each of the inner track, outer track, berm and sidecast.

**3.3.2 Stock type, size and planting method.** The Douglas-fir seedlings were 2+0 bareroot stock and the lodgepole pine were 1+0 Styroblock 213 plugs. 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.

**3.3.3 Monitoring and maintenance.** Heights and ground-level diameters of all seedlings were measured immediately after planting and after each growing season for 5 years. A final measurement was made after the eighth year. Seedling condition was assessed at the same time as measurements were made and dead seedlings were recorded and removed. After the third growing season, competing vegetation was cut down once each year. After the fifth season, seedlings were thinned to a minimum spacing of 2 x 2 m.

**3.3.4 Free carbonates.** The presence of free carbonates was tested at the site of each planted seedling 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).

**3.3.5 Vegetation.** Characteristics of vegetation by species and layers were measured using procedures outlined by Walmsley *et al.* (1980). Pre-planting (1984) and unlogged stand vegetation was assessed using mil-acre (4.05 m<sup>2</sup>) plots established at 30 m intervals along transects. In each of 1985, 1986 and 1987, 80 mil-acre, tree-centred, sub-plots were surveyed within the established plots, 10 each on the upper and lower undisturbed soil and the inner and outer tracks and 20 each on the berm and sidecast. All plants identified in each disturbance category and in the adjacent unlogged stand were used to produce dissimilarity percentages (PD) (Pielou 1984). Additionally, the composition of plants found in over 40% of the plots within a disturbance category over the 3 years of observation were tabulated by soil disturbance categories.

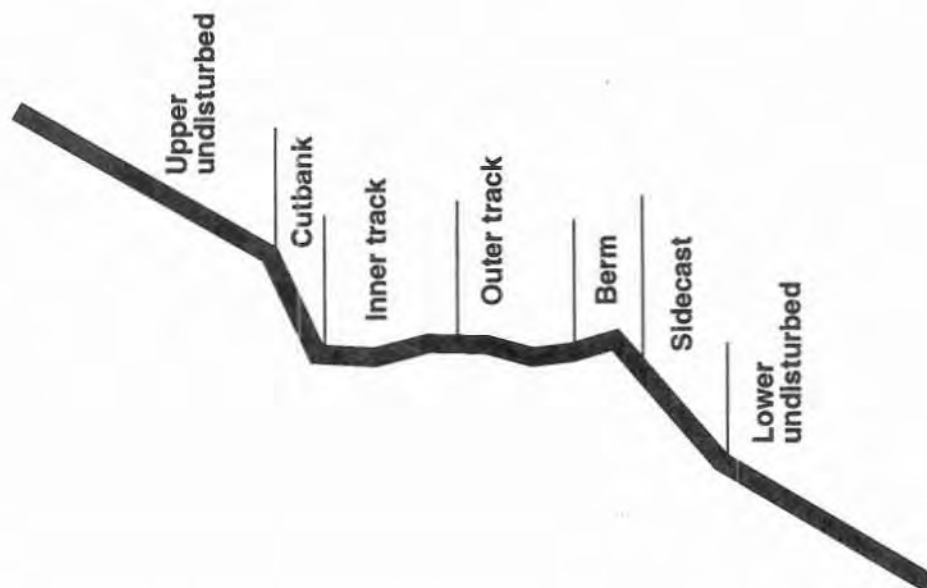


Fig. 2. Skidroad and adjacent undisturbed soil categories.



**3.3.6 Plant moisture stress.** In late July 1989 (the fifth growing season), six seedlings each of Douglas-fir and lodgepole pine were randomly selected from one of the three plots in each of the upper undisturbed soil, inner track, outer track, berm, sidecast and lower undisturbed soil for pre-dawn and mid-day plant moisture stress measurements using a pressure chamber (Waring and Cleary 1967). In all, 36 seedlings of each species were tested.

**3.3.7 Soil water.** Gravimetric soil water contents were determined for 0-10 and 10-20 cm depths concurrently with the plant moisture stress tests. Samples were taken within 25 cm of the base of each of the 72 seedlings used in the stress tests. Additionally, volumetric soil water content (top 20 cm of mineral soil) was measured in early May 1987 with an Instrument for Reflectometry Analysis of Moisture in Soils (IRAMS) (Topp *et al.* 1984). Moisture probes were made close to six randomly selected seedlings in each disturbance category in one of the plots.

**3.3.8 Foliage nutrients and needle weights.** Samples of current year's foliage were taken for nutrient analysis in the fall of 1989 (after five growing seasons) from 6 seedlings of each species per plot for each of the upper undisturbed soil, inner track, outer track, berm, sidecast and lower undisturbed soil. A total of 216 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 a 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.

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 Analyses

Chi-square tests were applied to test differences in survival of trees planted on the different disturbance categories. 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). Pearson correlation coefficients were used to determine significant correlations between selected soil characteristics and between selected seedling responses and soil characteristics. Multiple linear regression analyses were conducted to test the predictability of soil bulk density from other soil measures.

## 4.0 RESULTS

### 4.1 Undisturbed Soil Profile Characteristics

The soil, an Orthic Eutric Brunisol (Agriculture Canada Expert Committee on Soil Survey 1987), developed on a stony, calcareous, glacial till deposit with a 15-20 cm capping of non-calcareous colluvium. This disjunct soil layer caused some abrupt changes in the trends of chemical characteristics with depth (Fig. 3). The thin (4 cm) humus was a hemimor (Klinka *et al.* 1981) with an organic carbon content of 41%, total nitrogen content of 1.99% and a C/N ratio of 21. Mineral soil textures were loams to silt loams with sand content of 25-37%, silt content of 44-63% and clay content of 12-19%. Visually estimated coarse fragment content ranged from 2 to 5% in the capping and from 30 to 60% in the till. The latter was strongly calcareous at and below an average depth of 38 cm; its carbonate equivalences ranged from 28 to 40% and its pH ( $\text{CaCl}_2$ ) averaged 6.7 as compared with a range from 5.2 to 5.6 in the surface mineral soil (Fig. 3 D). Organic carbon and nitrogen and C/N ratios of the mineral soil all tended to decrease with depth (Figs. 3 A, B, C).

All of the 11 shallower pits dug throughout the study area tested positively for free carbonates. The first reaction to dilute HCl occurred at an average depth in mineral soil of 12 cm and a strong reaction at an average depth of 35 cm.

By using keys developed for rating the sensitivity of forest sites to soil disturbance (Lewis *et al.* 1989), the study site was rated as moderately sensitive to



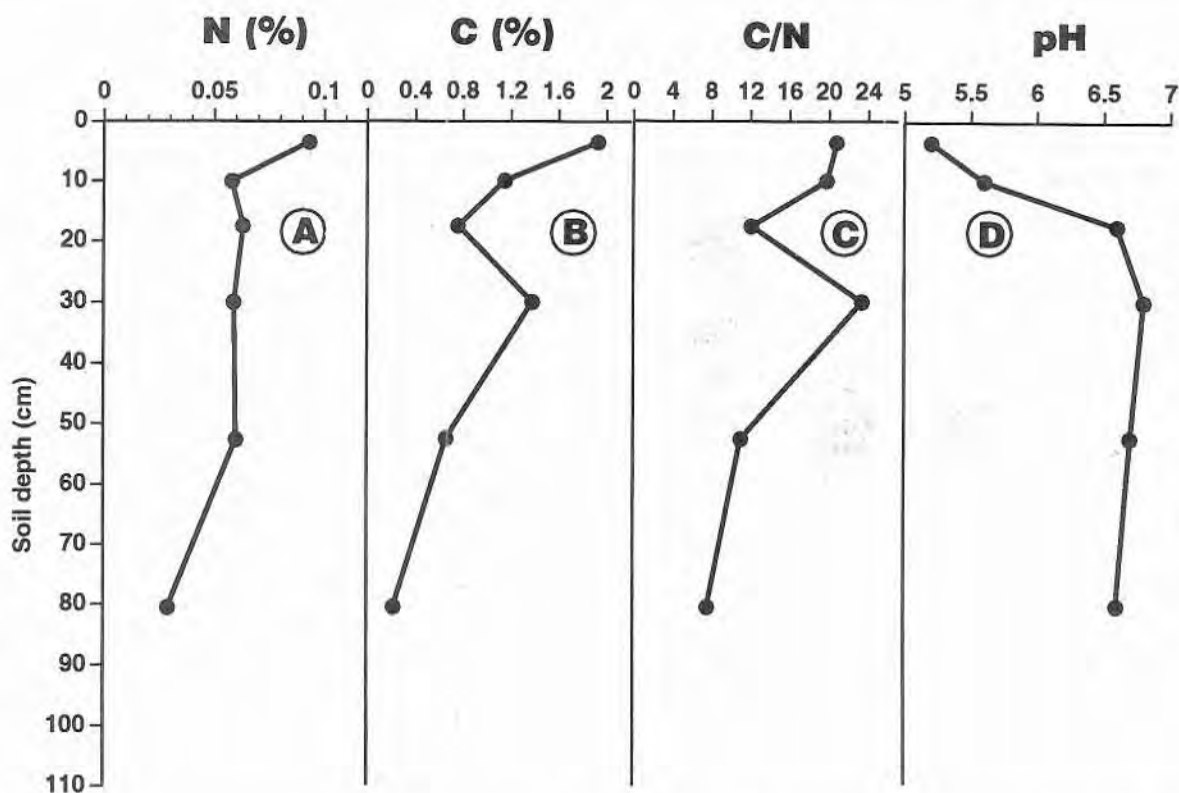


Fig. 3. Trends in some chemical characteristics with increasing depth of mineral soil in an undisturbed soil profile: A) Total nitrogen; B) Organic carbon; C) Carbon/nitrogen ratio; D) pH ( $\text{CaCl}_2$ ).

compaction, surface erosion and mass wasting and highly sensitive to displacement. The latter high rating was primarily due to an unfavorable substrate, i.e., soil horizons with free carbonates within 30 cm of the surface.

## 4.2 Ground Surface Conditions

All 94 points recorded on transects in the unlogged stand were classified as undisturbed (Table 1). Average depth of humus was 4 cm, 80% of which was classified as humified with no rotten wood, 4% as rotten wood, 12% as mixtures of rotten wood and humified material and 4% as not present or as miscellaneous types. Recent slash covered 15% and natural, rotting logs covered or were suspended above 20% of the ground surface. None of the 94 ground-surface points tested reacted to dilute HCl.

In the skidroad cutover, 48% of the 152 points recorded on transects were classified as disturbed (Table 1). Disturbance resulted mainly from skidroads, landings and skidtrails. Average depth of

humus on undisturbed spots in the skidded area was 3 cm, 53% of which was classified as humified with no rotten wood, 14% as rotten wood, 10% as mixtures of rotten wood and humified material, 5% as charcoal, 5% as litter only and 13% as not present or as miscellaneous other types. Recent slash covered 28% and natural, rotting logs covered or were suspended above 5% of the cutblock surface. Some 38% of the ground-surface points tested in the skidded area reacted to dilute HCl and 20% showed a strong reaction. For points on skidroads alone, 79% reacted to dilute HCl, including 41% with a strong reaction. Reaction increased in intensity with increasing depth of disturbance (Fig. 4).

## 4.3 Soil Bulk Density

Bulk density of the total soil at 0-10 cm was highest in the inner track, significantly higher than in undisturbed soil (Table 2). Total soil bulk density was also high in the outer track. Similar trends appeared for fine soil density but with no significant

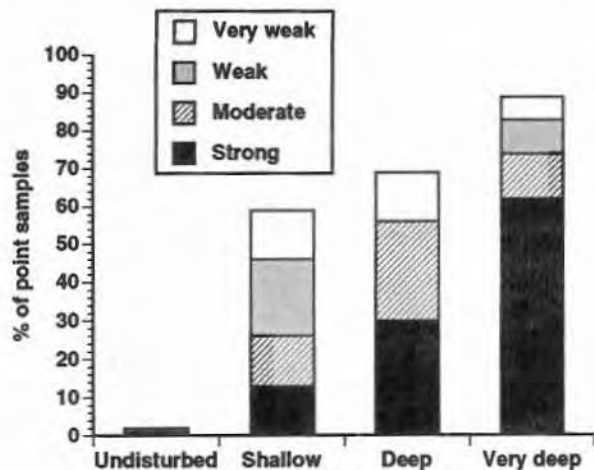


Fig. 4. Distribution of levels of soil carbonate as indicated by reaction to HCl for three depths of soil disturbance and undisturbed soil. Shallow= <5 cm; Deep= 5-25 cm; Very deep= >25 cm. Basis: 151 point-transect samples.

differences. At 10-20 cm, total soil densities were significantly higher for both the inner and outer tracks than for either the undisturbed soil or the berm. Fine soil densities for the undisturbed soil and for the inner and outer tracks were all significantly greater at 10-20 cm than in the berm.

#### 4.4 Penetrability

Soil resistance to penetration was significantly greater at depths of 2.5, 5.0, 7.5, 10.0, 12.5 and 15.0 cm in both the inner and outer tracks than in the undisturbed soil or berm (Fig. 5). At 0 and 20 cm, resistance in the berm was significantly less than for all other categories.

#### 4.5 Coarse Fragment Content

Coarse fragment content of the upper 10 cm of undisturbed soil was significantly less than for the top 10 cm of the inner and outer track and berm of

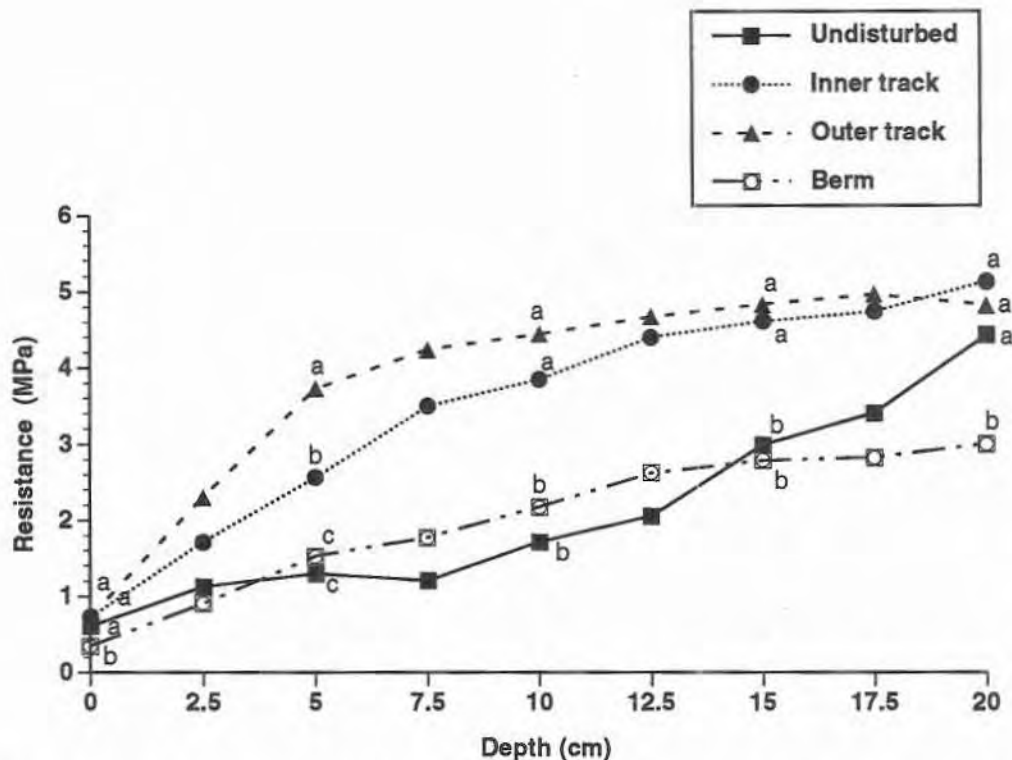


Fig. 5. Resistance (MPa) of inner track, outer track, berm and undisturbed mineral soil to penetration to a depth of 20 cm. Means within depth columns followed by the same letter are not significantly different at the 0.05 level. Basis: 24 probes for inner track, outer track and berm and 12 probes for undisturbed soil.

skidroads (Table 3). At 10-20 cm, coarse fragment content was significantly lower in undisturbed soil than in the inner track.

#### 4.6 Soil Correlations and Predictions

Total bulk density significantly and positively correlated with penetrometer resistance and coarse fragment content and negatively with soil water content (Table 4). Fine bulk density was significantly and positively correlated with penetrometer resistance and negatively with soil water content, but there was no significant correlation with coarse fragment content. Penetrometer resistance alone accounted for nearly 50% of the variation in total bulk density (Table 4). Resistance to penetration correlated negatively with organic carbon, total nitrogen and C/N ratio (Table 5) and positively with coarse fragment content (Table 4). Converting soil water content to a fine soil fraction basis did not improve the correlation of moisture content with resistance (Table 5).

The reliability of predictions of bulk density from parameters which may be easier to obtain was tested with multiple linear regression analyses and the following regressions obtained:

- 1a)  $BDT = 1.05 + 0.00195 \text{ RES} + 0.0056 \text{ CFR} - 0.0138 \text{ GSM}$  ( $R^2 = 0.65$ )
- b)  $BDT = 1.04 + 0.112 \text{ RES} + 0.0056 \text{ CFR} - 0.0138 \text{ GSM}$  ( $R^2 = 0.64$ )
- 2a)  $BDF = 1.13 + 0.00186 \text{ RES} - 0.0049 \text{ CFR} - 0.0128 \text{ GSM}$  ( $R^2 = 0.48$ )
- b)  $BDF = 1.13 + 0.106 \text{ RES} - 0.0049 \text{ CFR} - 0.0128 \text{ GSM}$  ( $R^2 = 0.49$ )

where: BDT= Total bulk density ( $\text{Mg/m}^3$ ); BDF = Fine bulk density ( $\text{Mg/m}^3$ ); RES = a) Penetration resistance as a direct penetrometer reading, b) Penetration resistance (MPa); CFR = Coarse fragment content (%); GSM = Gravimetric soil water content (%).

#### 4.7 Soil Chemical Characteristics

The most marked differences among disturbance categories in soil chemistry involved the presence or absence of carbonates and the pH level in the upper mineral soil (Table 6). No carbonates were detected in samples taken from the upper 20 cm of undisturbed mineral soil whereas average carbonate equivalences ranged from 2 to 8% on the skidroad categories. These differences are reflected in the significantly lower pH values in the undisturbed soil than in the

disturbed soil (Table 6). Additionally, a general trend was for higher organic contents and C/N ratios in disturbed compared with undisturbed mineral soil. This was particularly evident in the berm at a depth of 10-20 cm.

The pH of the bulk density soil samples increased significantly with increasing reaction to dilute HCl from none to strong (Fig. 6). Measured carbonate equivalence also appeared to increase with increasing reaction but most of the increase occurred in the strong category and high variation precluded any significant differences.

#### 4.8 Carbonates at Planting Spots

A high proportion of planting spots on disturbed soil tested positively for free carbonates with little difference in response among the disturbed categories (Table 7). In contrast, a very low percentage of planting spots in undisturbed soil tested positively for free carbonates.

#### 4.9 Volumetric Soil Water Content

The outer track had a significantly greater volumetric soil water content at 0-20 cm depth when measured in early May than the upper and lower undisturbed categories and the sidecast (Fig. 7). The sidecast had the lowest soil moisture content, significantly less than both the inner and outer tracks.

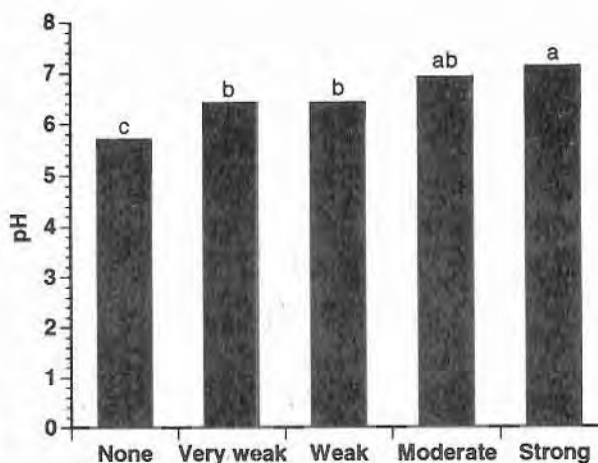


Fig. 6. Relationship of soil pH to dilute HCl reaction class. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level. Basis: 109 bulk density samples including samples from the stump uprooting area (Smith and Wass 1994).

#### 4.10 Seedling Survival

After 5 years, Douglas-fir exhibited significantly better survival in the skidroad running surface and the berm than in the sidecast or undisturbed ground (Table 8). Survival of lodgepole pine was significantly higher in the berm than in the lower undisturbed soil. There was no apparent relationship between the level of soil carbonates at planting spots and seedling survival. Most of the mortality, 94% for Douglas-fir and 80% for lodgepole pine, occurred during the first 2 years after planting.

#### 4.11 Seedling Growth

Measurements made immediately after planting showed that there were no significant differences in the sizes of Douglas-fir among disturbance categories. For lodgepole pine, seedlings planted in the berm were significantly taller (range 1.5-1.8 cm) than those planted in the inner and outer tracks and in undisturbed soil. This difference was not considered sufficiently large to affect subsequent analyses. Mean diameters and volumes of the lodgepole pine seedlings were not significantly different among disturbance categories.

Heights of Douglas-fir seedlings after five growing seasons on both the upper and lower undisturbed soil were significantly greater than

heights of seedlings on the inner and outer tracks of the skidroad (Table 9). Heights of Douglas-fir on the outer track, berm and sidecast were in turn significantly greater than those on the inner track. Both diameters and volumes were significantly less for seedlings planted in the inner track than for all other categories. After eight growing seasons, the mean height of Douglas-fir planted in the inner track was significantly less than for seedlings planted in the upper undisturbed soil and in sidecast (Table 9). The mean diameter of Douglas-fir growing in the inner track was significantly less than those planted in the sidecast.

Height growth of lodgepole pine seedlings growing in the upper undisturbed soil was significantly greater after five growing seasons than in the inner track, outer track and berm (Table 10). Height growth in the outer track, berm, sidecast and lower undisturbed was also significantly greater than that of seedlings growing in the inner track. Diameters and volumes were significantly lower for seedlings in the inner track than for seedlings in all other categories. After eight growing seasons, mean height, diameter and volume of lodgepole pine were all significantly less for the inner track than for the upper undisturbed category (Table 10).

Heights and volumes of Douglas-fir and lodgepole pine seedlings growing in disturbed soil

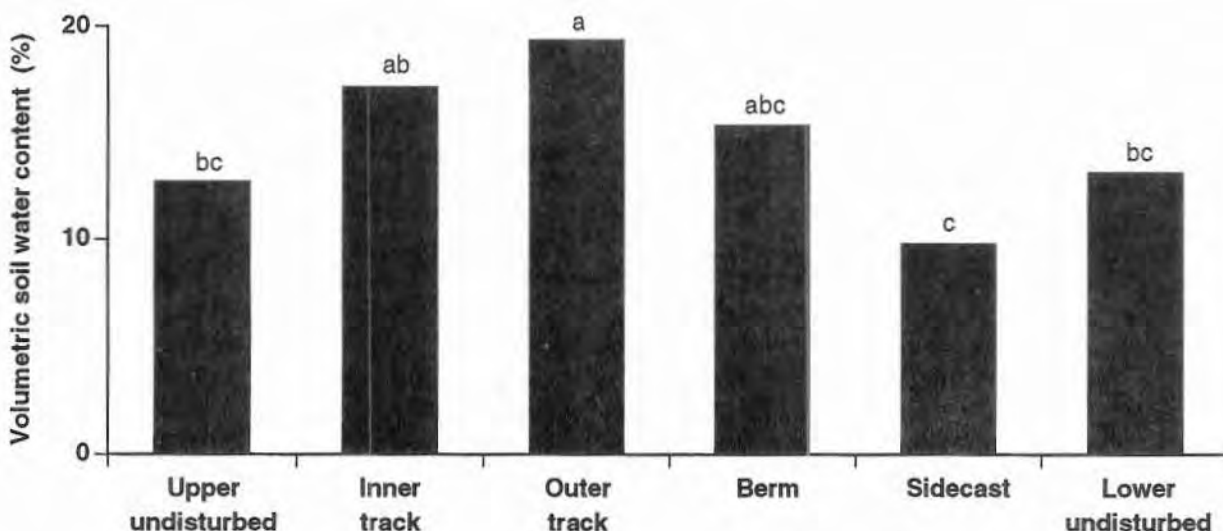


Fig. 7. Volumetric soil water content for the upper 20 cm of mineral soil on and adjacent to a skidroad surface as measured in early May, 1987. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level. Basis: 6 probes per disturbance category.



were compared with their growth in undisturbed soil for the period from 1985 to 1992 (Fig. 8). The detrimental effect of disturbed soil on the height growth of Douglas-fir was evident by the second year for seedlings growing in the inner and outer tracks and in the berm (Fig. 8A). Douglas-fir volumes tended to be higher for disturbed than for undisturbed soil for the first 3 years and then trended downward (Fig. 8B). By 1989, average Douglas-fir height for the inner track was only 67% and volume only 47% of that for Douglas-fir growing in undisturbed soil,

but this increased to 75% and 62%, respectively, by 1992.

By the second year, lodgepole pine seedlings on all disturbed soils were showing reduced height and volume growth relative to those growing in undisturbed soil (Figs. 8C, 8D). The greatest percentage reduction occurred by the second or third year followed by a slight moderation up to 1992. Height growth for lodgepole pine seedlings growing in the inner track was only 64% and volume only 50% of that of pine in undisturbed soil in the third year.

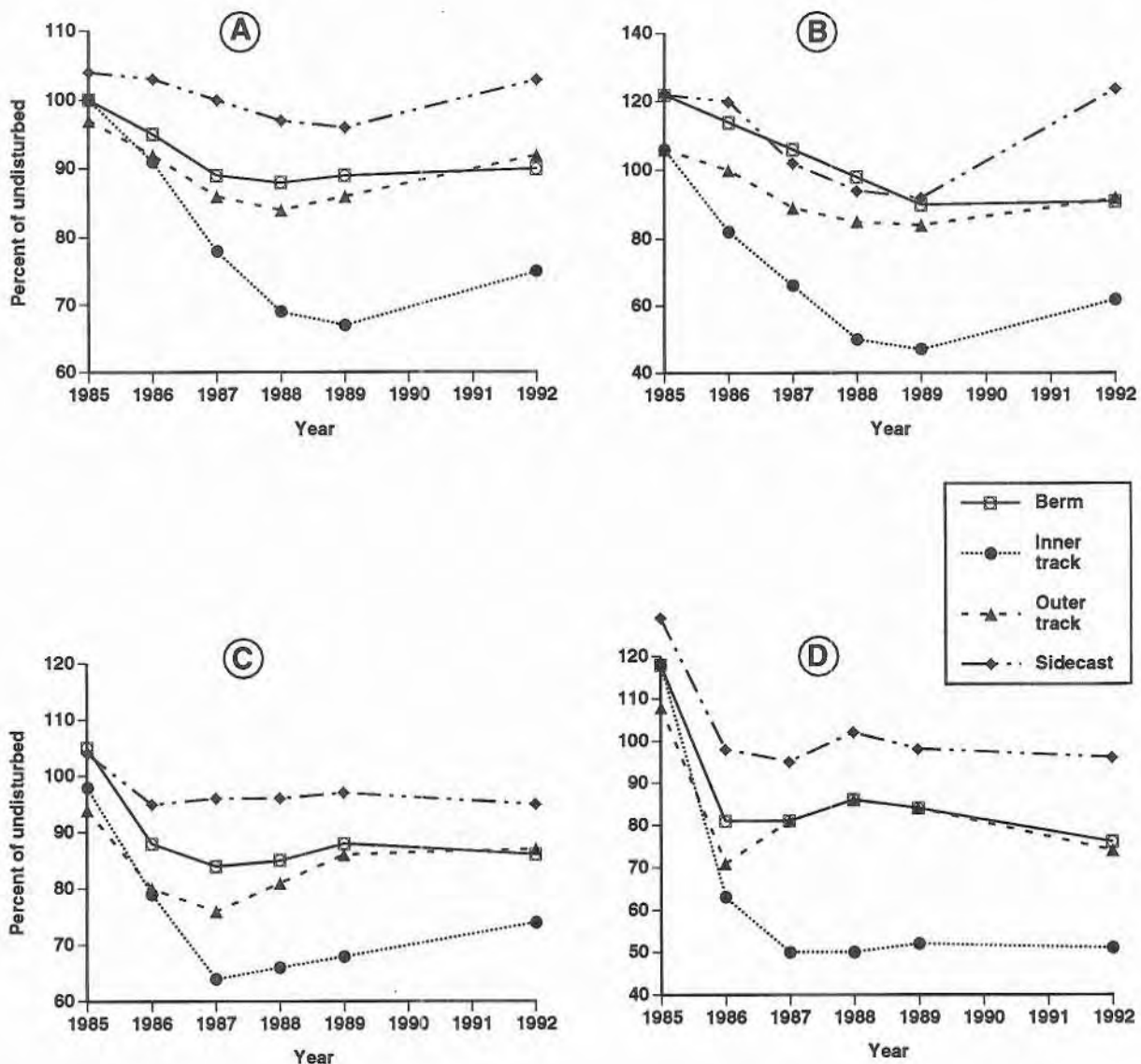


Figure 8. Height and volume of seedlings growing on disturbed soil as a percentage of height and volume of seedlings grown in an undisturbed soil: (A) height of Douglas-fir; (B) volume of Douglas-fir; (C) height of lodgepole pine; (D) volume of lodgepole pine.

By the fifth year, these percentages had risen slightly to 68% and 52% and in the eighth year were 74% and 51% for height and volume, respectively.

Seedling growth tended to be reduced with increasing carbonate reaction at the planting spots (Figs. 9-10). After 5 years, height growth was significantly less for Douglas-fir in planting spots with a moderate or strong reaction than for those in spots with a very weak or no reaction (Fig. 9). The trend was similar for volume but with no statistically significant differences. For lodgepole pine, height growth of seedlings associated with a strong reaction was significantly less than for those associated with a very weak or no reaction (Fig. 10). Again, the same trend existed for volume but without any significant differences.

#### 4.12 Foliage Weights and Nutrients

For both Douglas-fir and lodgepole pine, 100-needle weights were lowest for seedlings growing in the inner track (0.30 and 2.85 g, respectively) and highest in the outer track (0.36 and 3.23, respectively). However, differences were not significant for any comparisons.

The elements N, Zn and Mn were all appreciably lower in average concentration for foliage of Douglas-fir seedlings growing in the inner track than in any of the other categories but differences were not significant. The concentration of Ca in Douglas-fir foliage was significantly higher for seedlings growing

in the inner track and berm than in undisturbed soil (Table 11).

Based on Ballard and Carter's (1986) nutrient deficiency program, Douglas-fir foliage was on average severely deficient in N, possibly slightly to moderately deficient in Mg and possibly deficient in S for all disturbance categories. In addition, a possible slight deficiency in K was found in seedlings growing in the inner track.

For lodgepole pine, N concentration was lowest for foliage from seedlings growing in the inner track and sidecast, but differences among disturbance categories were not significant. The concentration of P for lodgepole pine foliage from seedlings growing in undisturbed soil was significantly higher than for foliage from seedlings planted in the sidecast (Table 12).

The concentration of K was also relatively low for foliage of seedlings growing in the inner track, berm and sidecast, significantly less than for foliage from seedlings growing in undisturbed soil. As with Douglas-fir, the concentration of Ca for foliage from seedlings planted in undisturbed soil was significantly less than that from the inner track. Foliage from seedlings planted in the inner track had significantly higher concentrations of Ca than for any other skidroad disturbance category (Table 12). Manganese concentration was particularly low for lodgepole pine foliage from skidroad surfaces, significantly less than from undisturbed soil.

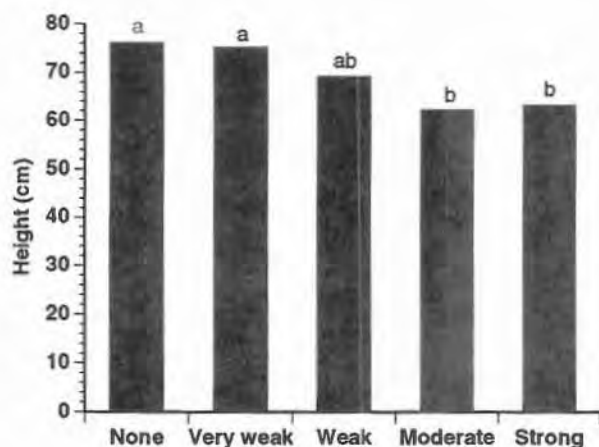


Fig. 9. Height growth of Douglas-fir by dilute HCl reaction classes. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level.

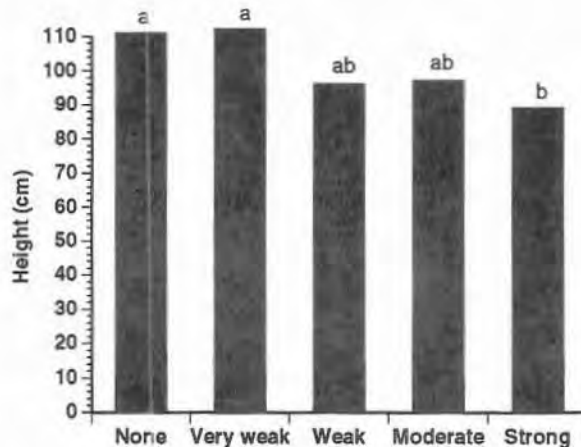


Fig. 10. Height growth of lodgepole pine by dilute HCl reaction classes. As represented by bars, means associated with the same letter are not significantly different at the 0.05 level.

Indications of nutrient deficiencies (Ballard and Carter 1986) were more common for lodgepole pine than for Douglas-fir. Lodgepole pine foliage was on average considered to be severely deficient in N, moderately deficient in P, possibly slightly to moderately deficient in Mg and likely deficient in active Fe for all disturbance categories. Sulphur was considered deficient for all disturbance categories except for seedlings growing in the outer track for which the diagnosis was "possibly deficient". Nitrogen-induced deficiencies in S resulting from nitrogen fertilization were also considered likely to occur. Additionally, K was diagnosed as possibly slightly deficient for seedlings in all disturbance categories except the undisturbed soil.

#### 4.13 Plant Moisture Stress

Significantly higher moisture stress occurred at mid-day for Douglas-fir seedlings growing in the upper undisturbed soil than for those in the outer track and sidecast (Table 13). Seedlings planted in the undisturbed soil showed best overnight recovery from moisture stress. Highest pre-dawn stress levels were recorded for seedlings growing in the outer track and berm, significantly higher than those recorded for

seedlings in the lower undisturbed category. There were no significant differences in pre-dawn or mid-day moisture stress levels for lodgepole pine.

Diameter and volume of Douglas-fir correlated negatively with mid-day moisture stress levels and negatively with the difference between pre-dawn and mid-day values (Table 14). Diameter correlated positively with pre-dawn levels. Gravimetric soil water contents correlated negatively with pre-dawn moisture stress and positively with the difference between pre-dawn and mid-day values.

Moisture stress values were not correlated with lodgepole pine growth (Table 15). Gravimetric soil moisture content correlated negatively with pre-dawn and mid-day stress measurements.

#### 4.14 Vegetation

The average total vegetative cover in the adjacent unlogged stand, 95%, was used as the unharvested starting point (Fig. 11). Forest harvesting reduced cover drastically, particularly on skidroad surfaces. Recovery was steady in the 3 years of measurement but with a marked lag in the case of the inner track (Fig. 11), with cover only about 50% that of the other

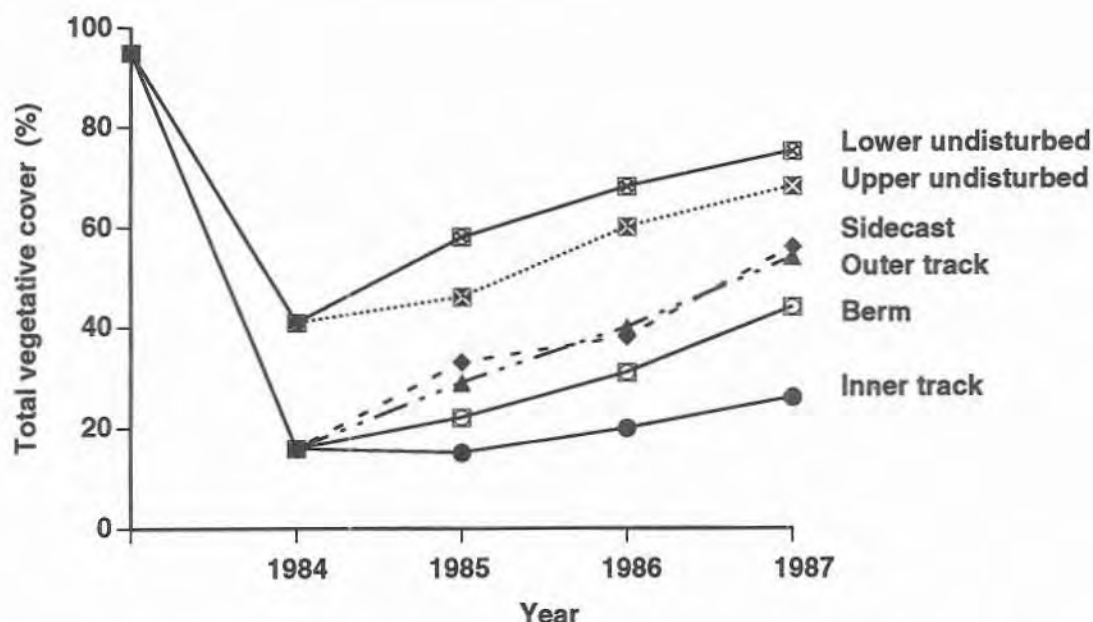


Fig. 11. Trends in total vegetative cover following clearcut logging for undisturbed soil and for four skidroad components. Initial cover (95%) comes from an adjacent unlogged stand.

skidroad segments and 33% that of logged but otherwise undisturbed soil.

As indicated by percentage dissimilarity measures, vegetation composition and cover were least similar between the undisturbed soil (both logged and unlogged) and the inner track (Table 16). Vegetation on the inner track was also quite different than that on the skidroad sidecast. Least dissimilar vegetation occurred on the upper and lower undisturbed soil and in comparisons of outer track and berm, outer track and sidecast, and berm and sidecast.

The composition of frequently occurring plant species, i.e., those present in more than 40% of sampled plots of a particular disturbance category, differed markedly among disturbance categories and between unlogged and logged plots (Table 17). As indicated by dissimilarity measures, the inner track was the most distinct of the disturbed categories with respect to frequently occurring species. Unexpectedly, some plant species were found frequently on the upper undisturbed soil but not frequently on the lower undisturbed soil.

Species occurring frequently only in the unlogged stand were *Shepherdia canadensis* (L.) Nutt., and *Pleurozium schreberi* (Brid.) Mitt. Species occurring frequently only in the unlogged stand or on undisturbed soil in the cutover were *Acer glabrum* Torr. and *Mahonia aquifolium* (Pursh) Nutt. (Table 17). *Populus tremuloides* Michx. was frequent only on undisturbed soil in logged areas. *Disporum trachycarpum* (Wats.) Benth. & Hook. established frequently under the unlogged stand, and in the logged stand on undisturbed soil and sidecast. *Aralia nudicaulis* L. was not found frequently in the unlogged stand but was frequent on undisturbed soil and on sidecast in the cutover. *Ceanothus sanguineus* Pursh was found frequently on all disturbed surfaces except the skidroad inner and outer tracks. *Rubus idaeus* L. and *Rubus parviflorus* Nutt. were frequently present on all disturbance categories except the inner track. Species occurring frequently on all disturbance categories and in the unlogged stand were *Spiraea betulifolia* Pall. and *Paxistima myrsinites* (Pursh) Raf. *Epilobium minutum* Lindley ex W.J. Hook., *E. angustifolium* L. and, except for the lower undisturbed, *Aster conspicuus* Lindley in Hook. occurred frequently on all disturbance categories. *Populus trichocarpa* Torr. & Gray ex Hook., was frequent only on the inner and outer track disturbed surfaces. *Cirsium vulgare* (Savi) Ten. and *Taraxacum* spp. Wiggers occurred frequently on all disturbed categories but not on undisturbed soil and *Pohlia*

*nutans* (Hedw.) Lindb. occurred frequently only on the outer track.

## 5.0 DISCUSSION AND CONCLUSIONS

The occurrence of calcareous horizons close to the soil surface in the study area results in a high susceptibility to degradation from soil displacement. Coupled with this is a moderate susceptibility to degradation of the loamy soil from mechanical compaction. Construction of skidroads along the contour and their subsequent use severely test both these susceptibilities. Soil displacement greatly increased the presence of free carbonates in the soil surface; the deeper the displacement, the higher the indicated concentration of carbonates. This result is logical given the relatively shallow, non-calcareous soil horizons at the surface in undisturbed profiles and the abrupt shift to calcareous horizons at 15-20 cm depth. These high carbonate levels in disturbed soil (up to 7.8% for the inner track at 10-20 cm depth) were reflected in significantly higher pH values (7.0 for inner track) than in the undisturbed soil (5.3).

In addition to having high carbonate levels, soils on the running surface of skidroads were considerably denser and less penetrable to a depth of at least 20 cm than for equivalent depths in undisturbed mineral soil. This resulted from displacement of topsoil and exposure of naturally dense subsoil and from mechanical compaction by road building and skidding machines. On the skidroad running surface, mean bulk density exceeded levels considered significantly detrimental to tree growth (i.e.,  $>1.4 \text{ Mg/m}^3$ ) (Heilman 1981; Gent *et al.* 1983; Carr 1987). Similar differences existed with fine soil bulk density but with no statistical significance. A significantly greater coarse fragment content, particularly on the inner track compared with the surface horizons of undisturbed soil, contributed to these high bulk densities. Resistance to penetration was significantly greater for the inner and outer tracks than for the berm and the undisturbed soil for depths from 5 to 15 cm. At 20 cm, the undisturbed soil was as penetrable as the tracks and less penetrable than the berm. Resistances were generally high relative to levels determined for other study areas (Smith and Wass 1991). Since a smaller cone was used in this study, the relative contribution of friction to resistance at the cone edge would be increased and direct comparisons with the earlier study should not be made. However, the results represent a good relative comparison



within individual studies. Reasonably good correlation between total bulk density and resistance to penetration supports the use of penetrometers to estimate density in soil disturbance surveys, at least to compare treatment responses in a relative manner.

The poor physical and chemical condition of the disturbed soil, particularly at the inner track, translates into reduced growth rates for Douglas-fir and lodgepole pine seedlings. After eight growing seasons, Douglas-fir planted in the inner track averaged 25% less in height and 38% less in volume than those planted in undisturbed soil. Height and volume reductions were less for the outer track (8 and 8%, respectively) and berm (10 and 9%, respectively). Douglas-fir seedlings grew faster on the sidecast than on undisturbed soil (3 and 24%, respectively). After eight growing seasons, lodgepole pine planted in the inner track averaged 26% less in height and 49% less in volume than those planted in undisturbed soil. Height and volume reductions were less for the outer track (13 and 26%, respectively), berm (14 and 24%, respectively) and sidecast (5 and 4%, respectively).

These trends confirm results from retrospective surveys on calcareous soils dealing with Douglas-fir, Engelmann spruce and subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) (Smith and Wass 1979, 1980) and, in one of three sites, lodgepole pine (Thompson 1990). In the former two studies, tree growth losses based on a 32% cover of skidroads (as taken from Smith and Wass 1976) ranged from 8 to 12% for Douglas-fir as prorated over whole clearcuts. Using a similar density of skidroads and the eighth-year data, the growth reduction caused by skidroads and prorated over the whole clearcut for Douglas-fir for this study would be 4% based on height and 3% based on volume. For lodgepole pine, reductions would be 5% for height and 9% for volume. The lower losses estimated in this study relative to the 1979 and 1980 studies may have resulted from a lower proportion of very deep (> 25 cm) soil disturbance, i.e., 52% versus 66%. In this study, growth of Douglas-fir shows a marked and lodgepole pine a slight upward trend on disturbed soil over the last 3 years relative to growth on undisturbed soil.

Even though a trend was shown for reduced seedling growth with increasing carbonate content, significant differences were restricted to height and then only to the extreme comparisons, i.e., no reaction and very weak reaction versus moderate or strong reaction. Soils reacting moderately or strongly to dilute HCl had average pH values >6.8 and carbonate equivalence levels >1.5%. Seedling growth would be

expected to decrease with increasing carbonate content and pH as a result of a reduction in availability of nutrients, particularly Fe, P and Mn. In this study, foliage of lodgepole pine growing in undisturbed soil had a significantly higher concentration of Mn than when growing in the higher pH soils of the skidroad disturbance categories.

Clearcutting and yarding operations reduced the cover of natural, rotting logs by 75% but also increased the proportion of surface organic layers containing rotten wood by 75% (from 8% to 14%). This substantial redistribution of rotten wood during logging operations has been reported previously for coastal forests (Smith and Wass 1983; Smith *et al.* 1986). As a result of this redistribution, higher organic C and N concentrations and C/N ratios were recorded for the outer track and especially the berm than for undisturbed mineral soil. This result is consistent with studies on disturbance caused by stump uprooting (Smith and Wass 1991, 1994). These disturbance categories result from the removal (gouging) of soil material and its deposit in a new location. These deposits incorporate various amounts of relatively undecomposed wood originally present on the soil surface or added during skidroad construction and associated tree felling and skidding.

Despite the significant differences in seedling growth on the inner track compared with the undisturbed soil and with other disturbance categories, no significant differences were measured in 100-needle weights, though there was a trend for lower weights for inner track trees. Significantly higher Ca content in foliage from Douglas-fir growing in the inner track than from those growing in undisturbed soil and of higher Ca content in foliage from lodgepole pine in the inner track than on all other disturbance categories, reflects the high carbonate content in inner track soils. The nutrients P, K, and Mn were significantly higher in foliage from lodgepole pine growing in undisturbed soil than in several of the disturbed categories.

As found in an earlier study on soil disturbance (Smith and Wass 1991), plant moisture stress levels in lodgepole pine did not vary with disturbance category. For Douglas-fir, growth related best to the difference between pre-dawn and mid-day stresses, suggesting that the ability to recover overnight from daytime moisture stress was as important as the absolute highest levels reached.

The separation of the inner track as a markedly different substrate from the other disturbance classes and the undisturbed soil carried through to vegetation

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development. By 1987, total vegetative cover on the inner track was only 35-59% that found on any of the other categories. The composition of plant cover on the inner track was also considerably different than on other categories. It was most dissimilar of all disturbance categories to the undisturbed soil and most dissimilar within the disturbed soil categories.

The study confirms that seedling survival and growth on skidroads is strongly tied to the segment of the skidroad in which the seedlings are located. Survival of Douglas-fir seedlings, in particular, was uniformly lower on the sidecast and undisturbed soil than on the skidroad running surface and berm, possibly because of the higher soil water contents recorded in the spring for the latter two categories.

Compared with the productivity of undisturbed soil, seedling growth after 8 years was markedly reduced on the skidroad running surface, particularly the inner track. Part of this reduction can be related to reduced rooting depth, numbers of roots and root area in these dense soils (E.F. Wass and R.B. Smith. Impacts of soil disturbance on root systems of Douglas-fir and lodgepole pine seedlings. Manuscript in preparation). In contrast, better soil conditions in the sidecast allows growth that is comparable to that on undisturbed ground. These differences are important when determining overall effects of forestry operations, devising procedures and techniques to reduce detrimental effects and planning rehabilitation strategies.

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**Table 1.** Categories and depths of soil disturbance in the skidded site (Basis= 152 transect points) versus an unlogged stand bordering the cutblock (Basis= 94 transect points)

Treatment	Disturbance category*	Depth of soil disturbance**				Total
		None	S	D	VD	
----- % of area -----						
Unlogged	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
Skidded	Undisturbed	45	0	0	0	45
	Undisturbed (NL)	3	0	0	0	3
	Undisturbed (ST)	2	0	0	0	2
	Undisturbed (SL)	2	0	0	0	2
	Litter burned off	2	0	0	0	2
	Skidroad	0	1	10	12	23
	Skidtrail	0	4	2	1	7
	Landing***	0	1	2	9	12
	Other skidding disturb.	0	2	1	0	3
	Erosion	0	1	0	0	1
	54	9	15	22	100	

\* NL= Natural rotting log; TS= Tree stem; BR= Bedrock; ST= Stump; 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.

\*\*\* The landing serviced a greater area than included in this survey.

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

Disturbance category	No. of samples	Total soil		Fine soil	
		0-10 cm	10-20 cm	0-10 cm	10-20 cm
Undisturbed	3	0.99 b*	1.28 b	0.85a	1.11a
Inner track	6	1.62 a	1.81 a	1.23a	1.35a
Outer track	6	1.55 ab	1.69 a	1.16a	1.30a
Berm	6	1.24 ab	1.04 b	0.92a	0.73b

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



**Table 3.** Coarse fragment content of bulk density samples

Disturbance category	No. of samples	Depth	
		0-10 cm	10-20 cm
		----- % -----	
Undisturbed	3	20 b*	24 b
Inner track	6	48 a	52 a
Outer track	6	42 a	45 ab
Berm	6	39 a	40 ab

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

**Table 4.** Pearson Correlation Coefficients and probabilities (top and bottom line in each pair, respectively) for bulk density, resistance to penetration, coarse fragment content and gravimetric soil water content comparisons (Basis= 106 samples)\*

	BDT**	BDF	RES	CFR	GSW
BDT	1.00 0.00	0.88 0.00	0.70 0.00	0.49 0.00	-0.46 0.00
BDF		1.00 0.00	0.63 0.00	0.06 0.56	-0.34 0.00
RES			1.00 0.00	0.30 0.00	-0.18 0.07
CFR				1.00 0.00	-0.32 0.00
GSW					1.00 0.00

\* Includes bulk density samples from both the stump uprooting (Smith and Wass 1994) and skidroad treatments at Marl Creek.

\*\* BDT= Total bulk density; BDF= Fine bulk density; RES= Resistance to penetration; CFR= Coarse fragment content; GSW= Gravimetric soil water content.

**Table 5.** Pearson Correlation Coefficients and probabilities (top and bottom line in each pair, respectively) for resistance to penetration, gravimetric soil water content (based on fine soil fraction), organic carbon, total nitrogen, C/N ratio and pH comparisons (Basis= 106 samples)\*

	RES**	GSWF	C	N	C/N	pH
RES	1.00 0.00	-0.17 0.07	-0.25 0.01	-0.22 0.03	-0.30 0.00	0.25 0.01
GSWF		1.00 0.00	0.67 0.00	0.64 0.00	0.44 0.00	0.00 0.99
C			1.00 0.00	0.88 0.00	0.80 0.00	-0.01 0.88
N				1.00 0.00	0.50 0.00	0.04 0.65
C/N					1.00 0.00	-0.06 0.53
pH						1.00 0.00

\* Includes bulk density samples from both the stump uprooting (Smith and Wass 1994) and skidroad treatments at Marl Creek.

\*\* RES= Resistance to penetration; GSWF= Gravimetric soil water content based on fine soil fraction; C= Organic carbon; N= Total nitrogen.

**Table 6.** Chemical characteristics of bulk density soil samples (Basis= three samples for undisturbed and six samples for all other disturbance categories for each depth).

Disturbance category	Depth (cm)	Organic carbon (%)	Total nitrogen (%)	Carbon/nitrogen ratio	CO <sub>3</sub> (%)	pH
Undisturbed	0-10	1.9 a*	0.09 a	21.1 a	0.0	5.3 b
Inner track	"	1.9 a	0.08 a	20.9 a	5.8	7.0 a
Outer track	"	2.8 a	0.10 a	28.7 a	5.0	6.6 a
Berm	"	3.4 a	0.12 a	28.4 a	4.4	6.8 a
Undisturbed	10-20	1.0 b	0.07 b	14.9 b	0.0	5.3 b
Inner track	"	1.1 b	0.06 b	17.1 b	7.8	7.0 a
Outer track	"	1.8 b	0.08 b	19.6 b	6.8	6.6 a
Berm	"	5.0 a	0.16 a	31.6 a	1.6	6.3 a

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

**Table 7.** Carbonate reaction at planting spots

Disturbance category	No. of spots tested	Level of carbonate reaction				
		None	V. weak	Weak	Moderate	Strong
		----- % -----				
Upper undisturbed	292	91	3	3	1	2
Inner track	121	2	5	17	31	45
Outer track	120	0	7	8	27	58
Berm	120	1	3	4	39	53
Sidecast	123	4	2	15	28	51
Lower undisturbed	195	85	3	6	5	1

**Table 8.** Survival rates of Douglas-fir and lodgepole pine seedlings planted in four skidroad soil disturbance categories and on the upper and lower undisturbed ground after five growing seasons

Disturbance category	No. seedlings planted	Species	
		Douglas-fir	Lodgepole pine
		----- % survival -----	
Upper undisturbed	145	67 b*	92 ab
Inner track	60	87 a	94 ab
Outer track	60	93 a	96 ab
Berm	60	94 a	98 a
Sidecast	60	67 b	87 ab
Lower undisturbed	95	64 b	85 b

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

**Table 9.** Mean heights, ground-level diameters and volumes of Douglas-fir seedlings for four skidroad disturbance categories and the upper and lower undisturbed ground after five and eight growing seasons

Disturbance category	No. of seedlings	Height (cm)	Diameter (mm)	Volume* (cm <sup>3</sup> )
<u>After five growing seasons</u>				
Upper undisturbed	89	75.3 a**	18.1 a	77.8 a
Inner track	47	50.6 c	14.9 b	36.6 b
Outer track	50	65.3 b	17.9 a	65.7 a
Berm	51	67.6 ab	17.7 a	70.8 a
Sidecast	36	73.1 ab	18.2 a	71.8 a
Lower undisturbed	56	77.1 a	18.2 a	79.2 a
<u>After eight growing seasons</u>				
Upper undisturbed	35	152 a	40 ab	749 a
Inner track	18	109 b	33 b	413 a
Outer track	14	133 ab	39 ab	614 a
Berm	14	130 ab	38 ab	605 a
Sidecast	14	150 a	43 a	827 a
Lower undisturbed	22	135 ab	36 ab	531 a

\* Volume is mean of individual seedlings each calculated as:  $0.261799 \times \text{diameter}(\text{cm})^2 \times \text{seedling height}(\text{cm})$ .

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



**Table 10.** Mean heights, ground level diameters and volumes of lodgepole pine seedlings for four skidroad disturbance categories and the upper and lower undisturbed ground after five and eight growing seasons

Disturbance category	No. of seedlings	Height (cm)	Diameter (mm)	Volume* (cm <sup>3</sup> )
After five growing seasons				
Upper undisturbed	124	113.3 a**	25.9 a	223.8 a
Inner track	51	74.7 c	18.8 b	104.9 b
Outer track	52	94.4 b	23.2 a	171.4 a
Berm	53	97.0 b	23.0 a	170.0 a
Sidecast	47	106.3 ab	24.4 a	199.7 a
Lower undisturbed	73	105.1 ab	23.1 a	168.2 a
After eight growing seasons				
Upper undisturbed	37	231 a	53 a	1883 a
Inner track	14	161 b	41 b	851 b
Outer track	14	189 ab	48 ab	1234 ab
Berm	14	188 ab	46 ab	1258 ab
Sidecast	15	206 ab	50 ab	1592 ab
Lower undisturbed	22	194 ab	47 ab	1285 ab

\* Volume is mean of individual seedlings each calculated as:  $0.261799 \times \text{diameter}(\text{cm})^2 \times \text{seedling height}(\text{cm})$ .

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

**Table 11.** Concentration of nutrients in Douglas-fir foliage and statistically significant differences (0.05 level) among disturbance categories (Basis= 90 seedlings, 18 for each of the five disturbance categories)

Nutrient	Mean	Std. dev.	Significant differences
----- % -----			
N	1.21	0.18	None
P	0.167	0.030	None
K	0.85	0.18	None
Ca	0.41	0.10	Inner track & berm > undisturbed
Mg	0.089	0.015	None
S	0.127	0.026	None
----- ppm -----			
Zn	25.2	13.7	None
Mn	75.8	44.2	None
Fe	37.3	11.7	None

**Table 12.** Concentration of nutrients in lodgepole pine foliage and statistically significant differences (0.05 level) among disturbance categories (Basis= 90 seedlings, 18 for each of the five disturbance categories)

Nutrient	Mean	Std. dev.	Significant differences
	----- % -----		
N	1.12	0.21	None
P	0.111	0.017	Undisturbed > Sidecast
K	0.48	0.10	Undisturbed > Inner track, Berm & Sidecast
Ca	0.27	0.12	Inner track > Outer track, Berm, Sidecast & Undisturbed
Mg	0.074	0.016	None
S	0.118	0.023	None
	----- ppm -----		
Zn	33.4	15.1	None
Mn	60.3	29.0	Undisturbed > Inner & Outer track, Berm & Sidecast
Fe	27.8	11.5	None

**Table 13.** Mean pre-dawn and mid-day moisture stress values (MPa) for Douglas-fir and lodgepole pine seedlings on July 25-26, 1989, for four skidroad disturbance categories and the upper and lower undisturbed ground (Basis= six seedlings for each disturbance category)\*

Disturbance category	Douglas-fir		Lodgepole pine	
	Pre-dawn	Mid-day	Pre-dawn	Mid-day
Upper undisturbed	0.69 ab**	1.90 a	0.59 a	1.54 a
Inner track	0.64 ab	1.67 ab	0.68 a	1.64 a
Outer track	0.72 a	1.54 b	0.71 a	1.54 a
Berm	0.74 a	1.74 ab	0.71 a	1.58 a
Sidecast	0.61 ab	1.54 b	0.72 a	1.54 a
Lower undisturbed	0.55 b	1.70 ab	0.66 a	1.48 a

\* Weather was clear and warm both days with maximum temperature of 27°C and a minimum of 8°C. Humidities ranged from 30% during the day to 82% at night.

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

**Table 14.** Pearson Correlation Coefficients and probabilities (top and bottom line of each pair, respectively) for comparisons of pre-dawn, mid-day and mid-day minus pre-dawn plant moisture stress values for Douglas-fir seedlings with gravimetric soil water contents and 5-year seedling diameter, height and volume (Basis= 72 seedlings)\*

	AM**	PM	PM-AM	GWC	DIA	HT	VOL
AM	1.00 0.00	-0.05 0.65	-0.63 0.00	-0.37 0.00	0.27 0.02	0.11 0.36	0.21 0.07
PM		1.00 0.00	0.81 0.00	0.09 0.47	-0.34 0.00	-0.18 0.13	-0.31 0.01
PM-AM			1.00 0.00	0.28 0.02	-0.43 0.00	-0.21 0.08	-0.36 0.00
GWC				1.00 0.00	-0.31 0.01	0.05 0.69	-0.18 0.13
DIA					1.00 0.00	0.73 0.00	0.93 0.00
HT						1.00 0.00	0.83 0.00
VOL							1.00 0.00

\* Sample seedlings are from both the stump uprooting (Smith and Wass 1994) and skidroad treatments at Marl Creek.

\*\* AM= Pre-dawn moisture stress; PM= Mid-day moisture stress; PM-AM= Mid-day minus pre-dawn moisture stress; GWC= Gravimetric soil water content; DIA= Diameter; HT= Height; VOL= Volume.

**Table 15.** Pearson Correlation Coefficients and probabilities (top and bottom line of each pair, respectively) for comparisons of pre-dawn, mid-day and mid-day minus pre-dawn plant moisture stress values for lodgepole pine seedlings with gravimetric soil water contents and 5-year seedling diameter, height and volume (Basis= 71 seedlings)\*

	AM**	PM	PM-AM	GWC	DIA	HT	VOL
AM	1.00 0.00	0.09 0.47	-0.55 0.00	-0.40 0.00	0.14 0.25	-0.01 0.95	0.12 0.32
PM		1.00 0.00	0.79 0.00	-0.35 0.00	0.09 0.48	0.09 0.48	0.08 0.52
PM-AM			1.00 0.00	-0.05 0.70	-0.01 0.91	0.08 0.53	0.01 0.94
GWC				1.00 0.00	-0.15 0.21	-0.05 0.70	-0.13 0.29
DIA					1.00 0.00	0.75 0.00	0.96 0.00
HT						1.00 0.00	0.84 0.00
VOL							1.00 0.00

\* Sample seedlings are from both the stump uprooting (Smith and Wass 1994) and skidroad treatments at Marl Creek.

\*\* AM= Pre-dawn moisture stress; PM= Mid-day moisture stress; PM-AM= Mid-day minus pre-dawn moisture stress; GWC= Gravimetric soil water content; DIA= Diameter; HT= Height; VOL= Volume.



**Table 16.** Average dissimilarity indices (%) based on average vegetation composition and cover over 3 years (1985-87) for disturbance category comparisons (Basis= 20 subplots for berm and sidecast and 10 subplots for each of the other disturbance categories)

	Unlogged	Upper undisturbed	Lower undisturbed	Inner track	Outer track	Berm	Sidecast
Unlogged	0	73	80	90	80	85	76
Upper undisturbed		0	34	83	57	64	44
Lower undisturbed			0	86	58	58	44
Inner track				0	54	59	76
Outer track					0	38	40
Berm						0	40
Sidecast							0

**Table 17.** 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 six disturbance categories.

	Unlogged		Upper undisturbed		Lower undisturbed		Inner track		Outer track		Berm		Sidecast	
	F	C	F	C	F	C	F	C	F	C	F	C	F	C
<i>Shepherdia canadensis</i>	74	11	-	-	-	-	-	-	-	-	-	-	-	-
<i>Pleurozium schreberi</i>	53	2	-	-	-	-	-	-	-	-	-	-	-	-
<i>Acer glabrum</i>	42	7	47	5	-	-	-	-	-	-	-	-	-	-
<i>Mahonia aquifolium</i>	42	1	50	1	-	-	-	-	-	-	-	-	-	-
<i>Populus tremuloides</i>	-	-	73	8	-	-	-	-	-	-	-	-	-	-
<i>Disporum trachycarpum</i>	95	8	60	2	67	4	-	-	-	-	-	-	54	3
<i>Aralia nudicaulis</i>	-	-	67	1	70	6	-	-	-	-	-	-	70	3
<i>Ceanothus sanguineus</i>	-	-	93	10	60	15	-	-	-	-	51	3	51	3
<i>Rubus idaeus</i>	-	-	83	4	67	8	-	-	52	4	52	7	47	8
<i>Rubus parviflorus</i>	-	-	47	1	63	4	-	-	48	3	43	4	47	2
<i>Spiraea betulifolia</i>	74	5	100	17	100	17	52	1	93	7	70	2	93	8
<i>Paxistima myrsinites</i>	95	21	100	2	97	2	73	1	89	2	95	1	96	2
<i>Epilobium minutum</i>	-	-	53	1	70	1	73	1	59	1	75	1	56	1
<i>Epilobium angustifolium</i>	-	-	57	1	43	1	45	1	74	1	51	2	63	3
<i>Aster conspicuus</i>	-	-	47	1	-	-	58	1	52	2	48	1	54	2
<i>Pohlia nutans</i>	-	-	-	-	-	-	-	-	41	1	-	-	-	-
<i>Populus trichocarpa</i>	-	-	-	-	-	-	58	2	63	6	-	-	-	-
<i>Taraxacum</i> spp.	-	-	-	-	-	-	70	1	74	2	57	1	42	1
<i>Cirsium vulgare</i>	-	-	-	-	-	-	61	1	56	2	44	2	42	1