RESEARCH REPORT

21

Effects of Bladed Skid Roads on Soil Properties and Early Tree Growth on Two Steep Slopes in the Southern Interior of British Columbia

G. D. Hope

2001

British Columbia
Ministry of Forests
Research Program

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National Library of Canada Cataloguing in Publication Data

Hope, G. D. (Graeme d'Egville), 1951-

Effects of bladed skid roads on soil properties and early tree growth on two steep slopes in the southern interior of British Columbia

(Research report ; 21)

Includes bibliographical references: p.

ISBN 0-7726-4496-9

1. Forest roads - Environmental aspects - British Columbia – Vernon Region. 2. Forest soils - British Columbia – Vernon Region. 3. Trees - British Columbia – Vernon Region - Growth. I. British Columbia. Ministry of Forests. Research Branch. II. Series: Research report (British Columbia. Ministry of Forests. Research Branch) ; 21.

SD389.E33 2001 634.9'3 C2001-960061-5

Citation

Hope, G.D. 2001. Effects of bladed skid roads on soil properties and early tree growth on two steep slopes in the southern interior of British Columbia. Res. Br., B.C. Min. For., Victoria, B.C. Res. Rep. 21.

URL: http://www.for.gov.bc.ca/hfd/pubs/Docs/Rr/Rr21.htm

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SUMMARY

The effects of skid roads on soil physical and chemical properties, tree nutrition, and tree growth were studied at two steep sites with coarse-textured soils in the Interior Cedar–Hemlock zone east of Vernon, B.C. The study began in 1986 and continued for 11 years. Approximately one-third of each of the steep slope study areas was occupied by soil disturbances associated with construction and use of bladed skid roads. Treatment plots were established on five locations associated with skid roads: above and below the road, the inner and outer track of the road's running surface, and the skid road sidecast. Soil properties were measured before plantation establishment and during the first year of growth, and to a limited extent, after 10 years of growth. Seedling growth was measured at intervals between 1 and 10 years after establishment.

Whole soil bulk densities were increased by approximately 40% on the skid road surfaces. These bulk density increases were still apparent after 10 years. Although large relative increases were also evident in fine soil bulk densities, these bulk densities did not approach growth-limiting thresholds, except on the inner track at one site. Other soil physical properties, such as porosity, aeration, and water storage capacity were not reduced to below apparent threshold values. Soil moisture contents through the first growing season did not help to explain differences in the rates of tree growth. Although soil chemical content was reduced by displacement of the forest floor and surface mineral soil, soil chemical concentrations that remain may be sufficient to adequately support tree growth.

Tree growth over the 10-year period was best on the skid road sidecast and outer trail positions at both sites. Inner track growth was comparable to that of the non-track areas. Foliar nutrients did not indicate any possible deficiencies specific to the disturbed areas.

In these moist to wet ecosystems, the early growth of trees on the skid roads constructed on these very coarse-textured soils is enhanced relative to the undisturbed areas. However, the results should not be generalized and extrapolated to soils and ecological conditions outside those of the study areas. Ongoing mass wasting associated with the constructed skid roads may be reducing overall site productivity.

ACKNOWLEDGEMENTS

This study was established as a joint research project between the Vernon Forest District and the Research Section of the Kamloops Forest Region. Bob Mitchell, retired soil scientist for the Kamloops Forest Region, conceived the original idea for the study and administered the project from 1986 to 1994. Bill Carr, of Carr Environmental Services, designed the study and was technical advisor for the project from 1986 to 1991. Rick Smith of the Vernon Forest District served as the district contact for the project, and provided both field assistance and financial support. Because of the unfavourable terrain and climate of the study area, data collection has been a difficult and time-consuming task. Fraser Russell and Barbara Zimonick have provided the bulk of field and data analysis support. I. Wright, C. Gordon, K. McKenzie, A. Cline, T. Redding, T. Blenner-Hassett, D. McAllister, J. Boffey, T. Deadmarsh, and C. Sinneman have provided additional assistance. Wendy Bergerud provided advice on statistical analyses.

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1 INTRODUCTION

The conventional method of timber harvesting in the interior of British Columbia is with ground-based equipment, primarily skidders and tractors. Of the approximately 1.5 million hectares of forest land harvested in the interior regions from 1976 to 1986, ground-skidding (also known as conventional harvesting) was utilized on 97% of the area (Utzig and Walmsley 1988). Ground-based logging systems typically require the construction of landings and use of skid trails. When ground-based methods are used on slopes greater than 35%, construction of skid roads (excavated and bladed trails) is usually required.

In the early to mid-1980s in British Columbia, concern was raised over the effect of the constructed skid roads on forest productivity (Smith and Wass 1979; Utzig and Walmsley 1988). Early studies often found that the percentage of cutblock area in skid roads, primarily on steep slope sites, approached or exceeded 30% (Smith and Wass 1976; Schwab and Watt 1981; McLeod and Hoffman 1984). As guidelines for soil conservation were introduced (Interior Forest Harvesting Council 1989), these percentages were reduced. A survey of cutblocks throughout the interior forest regions found that the percentage of conventionally logged blocks occupied by disturbed soils in the form of landings, skid roads, and skid trails ranged from 6.7 to 9.4% for winter logging and from 10.6 to 16.1% for summer logging (Thompson and Osberg 1992). Higher levels of disturbance were generally associated with steeper terrain.

The categories of soil disturbance considered detrimental to soil and site productivity have differed throughout the years in British Columbia. Constructed landings, bladed or excavated trails (skid roads), and heavily travelled skid trails are now limited in area and regarded as soil disturbance under the Forest Practices Code of British Columbia. Excavated and bladed trails are considered detrimental from the top of the cutslope to the outside of the running surface, and also include the fill slope if the sidecast soil material is unfavourable to tree growth. In addition, these skid road structures must now be rehabilitated after use.

Alteration of both the physical and chemical properties of soils by construction and use of excavated and bladed trails during ground-based harvesting has been widely studied. The scalping and displacement of nutrient-rich surface soil horizons can dramatically lower site nutrient capital, particularly of nitrogen and phosphorus (Carr 1987; Arnott et al. 1988). Additionally, soils on these trails are subject to compactive forces during operations, which can result in increased soil densities and resistance to root penetration, and altered soil macropore–micropore relationships (Greacan and Sands 1980; Senyk and Craigdallie 1997). The degree and extent of change in soil physical and chemical properties depends on site conditions and soil texture during the construction or operational phases (van der Weert 1974).

The effects of soil property alteration on tree growth are not always consistent. Different studies have produced conflicting results, but reduced forest productivity is evident in many cases (Froehlich 1979; Wert and Thomas 1981; Jakobsen 1983; Carr 1987; Arnott et al. 1988). However, in other situations, no measurable effects on tree growth have been found (Miller et al. 1996). The effects on tree growth and site productivity appear to involve a complex interaction between climate, soil texture, changes in soil physical and chemical properties, and tree species (Greacan and Sands 1980). Miller et al. (1996) suggest that the effects may be site and machinery specific.

The initial objectives of this research project were to quantify the changes in soil properties associated with skid road construction and use on steep slopes in the wetter areas of the southern interior of British Columbia, and to monitor the subsequent effect on juvenile plantation performance.

An unpublished report was initially produced for the study (Carr and Mitchell 1994) and some results from that report are included in the present summary of the first 10 years after establishment.

2 STUDY AREA

The study area is located at two sites located approximately 80 km southeast of Vernon in the southern interior of British Columbia. Both sites are in the Vernon Forest District. The Railroad Creek site (hereafter referred to as “Railroad”) is located in the upper Monashee Creek drainage at an elevation of 1450 m. The Winnifred Creek site (hereafter referred to as “Winnifred”) is located in the upper Kettle River drainage at an elevation of 1360 m. Both sites occur within the Monashee Mountains of the Columbia Mountains, Southern Plateau and Mountain Physiographic Region (Holland 1976), and both are within the Shuswap Moist Warm Interior Cedar–Hemlock variant (ICHmw2)(Lloyd et al. 1990).

The Railroad study site is a 13-ha clearcut on steep to very steep slopes with a northeast aspect. The Winnifred study site is a 27-ha clearcut on a drier, moderately steep to steep south aspect. Both sites occur on soils that are coarse textured and very gravelly in both topsoils and subsoils (Table 1). Winnifred soils are derived from granitic glacial till, Railroad soils from metasedimentary colluvium. Soils at Winnifred are classified as Orthic Dystric Brunisols, those at Railroad as Orthic Humo-Ferric Podzols (Soil Classification Working Group 1998). The general soil and vegetation characteristics of the sites are presented in Table 1. Appendix 1 contains more detailed descriptions of each site.

The Railroad and Winnifred sites were logged during the summer using conventional ground-harvesting systems (rubber-tired skidders) in 1980 and 1983, respectively. At Winnifred, the broken terrain dictated the use of a dendritic skidding pattern. On the more uniform terrain at Railroad, a contour skid road pattern was used. Railroad was broadcast burned in 1983 and Winnifred was left untreated for planting.

The present study was initiated in 1986. The soil disturbance surveys were conducted in 1986. Initial sampling of soils occurred in the fall of 1986. The plantations were established in the spring of 1987.

TABLE 1 *Soil and vegetation characteristics of the study sites*

Site property	Railroad	Winnifred
% slope[1]	65 (60–90)	45 (30–70)
Soil texture	loamy sand	loamy sand
% coarse fragments[2]	45	35
Soil moisture regime	submesic to mesic	subxeric to submesic
Dominant vegetation	fireweed /bluejoint reedgrass	falsebox - pinegrass

[1] Mean (and range).

[2] By volume in top 20 cm of mineral soil.

3 METHODS AND SAMPLING PROCEDURES

3.1 SURVEY OF SOIL DISTURBANCE

A ground survey of soil disturbance classes was conducted using a modification of the line-transect system developed for root rot surveys by Bloomberg et al. (1980). From an established baseline at each study site, parallel survey lines with a random between-line spacing were established. At Winnifred, eight lines with a total length of 2764 m were sampled, and at Railroad, 12 lines totalling 2649 m in length were sampled. Along each survey line, the length of the line within a soil disturbance category was recorded to the nearest 0.5 m.

Both disturbance cause and class were recorded. The disturbance causes included were: undisturbed; main or branch road; landing; skid road (bladed structure) including the cutslope, inner track, outer track, or sidecast or berm; and other disturbance. At Winnifred, non-bladed trails or dispersed disturbances were recorded as shallow disturbances. At Railroad, all traffic was confined to skid roads.

Each disturbance cause was also assessed for disturbance class or depth. These classes included nil, shallow (1–5 cm), deep (6–25 cm), and very deep (> 25 cm). The data are presented as line length attributed to a particular disturbance cause as a percentage of the total line length surveyed in the block.

3.2 SOIL SAMPLING AND TREE GROWTH

3.2.1 Experimental design and treatments

At each site, eight representative, uniform, 50-m-long sections of skid road and their adjacent undisturbed areas were selected as plots for detailed soil and tree growth assessment. Each plot contained at least four treatments (soil disturbance causes). An extra treatment was sampled at Winnifred. The treatments sampled were:

1. undisturbed area above skid road,
2. skid road inner track,
3. skid road outer track,
4. skid road sidecast or berm,
5. undisturbed area below skid road (at Winnifred only)

3.2.2 Soil physical and chemical properties

In year 0 (1986), four subsampling locations, for soil bulk density and nutrient level determination, were randomly established within each treatment plot. Bulk density in year 0 was measured using a single-probe nuclear density meter (Campbell Pacific MC-1) with probe depths of 10, 20, and 30 cm. Standard procedures were used for wet density, moisture content, and dry density calculation.

In year 11 (1997), soil bulk density was sampled in three treatments (inner track, outer track, and sidecast) at three stratified random locations per treatment. Bulk densities were determined using the excavation method for the 0–20 cm mineral soil depth only. Approximately 1.5 L of soil was excavated by hand and the volume of the excavation determined with water. Oven-dry mass of the soil fractions greater than, and less than, 2 mm was then determined.

Soil porosity and moisture retention characteristics were determined on samples collected from one subsampling location per treatment in year 0. Soil samples were collected using steel rings 7.5 cm in diameter and 3.0 cm in depth. Samples were sealed in plastic wrap and transported to Soilcon Inc. (Richmond, B.C.) for analysis. Total porosity was calculated using the bulk density of the sample and particle density as determined using the Pycnometer method. Aeration porosity was calculated as the difference in volumetric water content between soil saturation and moisture retention at -10 J/kg, as determined from a five-point moisture retention curve. Available water storage capacity was calculated as the difference between volumetric water contents at potentials of -0.033 and -1.5 MPa (Fleming et al. 1994).

To analyze soil chemical properties, mineral soil (to a depth of 20 cm) was collected in year 0 at each subsample location using a 5-cm diameter soil corer. In the undisturbed treatment, a 78.5 cm^2 section of the forest floor was also collected. Samples were air-dried and sieved (< 2 mm, mineral soil) or ground (forest floor) before analysis. All chemical analysis was performed at the Ministry of Forests Laboratory in Victoria.

Mineral soils were analyzed for total nitrogen (N) using a semi-micro Kjeldahl digest followed by colorimetric determination (Kalra and Maynard 1991), available phosphorus (P) using the Bray P-1 method (Kalra and Maynard 1991), and extractable calcium (Ca), potassium (K), and magnesium (Mg) using Morgan's extractant (1.0 N NaOAc) followed by atomic absorption (Greweling and Peech 1960). Cation exchange capacity (CEC) was determined in 1.0 M ammonium acetate at pH 7.0 (Kalra and Maynard 1991). Soil pH was determined in 0.01 M $CaCl_2$. Forest floor total N, P, Ca, K, and Mg were determined on acid digests (Parkinson and Allen 1975) followed by colorimetric determination of N and P on a Technicon autoanalyzer and determination of Ca, K, and Mg by atomic absorption.

Gravimetric soil moisture contents were determined in three plots per site during the 1987 growing season (May–October). At one location in the three plots, surface mineral soil (0–10 cm) samples were collected, sieved, transported to Kamloops in air-tight sample tins, and oven-dried at 105° C for 24 hours. Moisture contents were determined as a percentage of the oven dry weight. Volumetric moisture contents were calculated using the equation:

$$\theta = (\text{bd-fine}) \times w$$

where θ is the volumetric soil water content, (bd-fine) is the bulk density of the < 2 mm mineral soil, and w is the gravimetric moisture content (Hillel 1980).

3.2.3 Regeneration performance

A row of at least 50 seedlings was planted during the spring of 1987 (year 1) in each treatment unit plot. Seedling spacing in the row was between 1 and 2 m. At Winnifred, the row consisted of 2-0 lodgepole pine (*Pinus contorta* var. *latifolia* [Engelm.]) and 2-0 Douglas-fir (*Pseudotsuga menziesii* var. *glauca* [Beissn.] Franco) planted at a ratio of 1:1. At Railroad, the row consisted of 2-0 lodgepole pine and 2-0 white spruce (*Picea glauca* [Moench] Voss) planted at a ratio of 1:1. Seedling survival, vigour, total height, and root collar diameter data were collected at one, two, three, five, and 10 growing seasons after planting.

3.2.4 Foliar nutrient concentration

Foliar nutrients were sampled in the autumn at the end of the fifth growing season (1991). A composite sample of the current-year's growth was collected from 10 random trees per species within each treatment plot. Samples were oven-dried at 70° C for 24 hr, and needle weight (per 100 needles for spruce and Douglas-fir, per 75 pairs for lodgepole pine) determined. Samples were ground before analysis at the Ministry of Forests Laboratory in Victoria. Foliar N was determined using a Leco analyzer. All other foliar nutrients were determined using ICP-AES equipment after acid oxidation (Kalra and Maynard 1991).

3.3 STATISTICAL ANALYSIS

Analysis of variance (ANOVA) was used to test for treatment differences among plot means. The data were analyzed as a randomized block design with plots treated as blocks, as shown in Table 2. Each site was tested separately. A significance level of p=0.05 was generally used (exceptions are noted in specific sections of the report) to test for significant differences. Multiple comparisons of soil differences, when appropriate, were made using Fisher's protected least significant difference (lsd) test at a 95% confidence level (Steel and Torrie 1980). Multiple comparisons of regeneration performance means were made using Duncan's multiple range test. Repeated measures analysis of seedling growth curves was carried out using multivariate analysis (Nemec 1996). Growth curves were tested for both between-plot and within-plot variation (Gumpertz and Brownie 1993). All data analysis was carried out using the SAS statistical system (SAS Institute 1989, 1996).

TABLE 2 *Analysis of variance model*

Source of variation	Df	Error
Plots (P)	7	—
Treatment (T)	4 (Winnifred) 3 (Railroad)	P * T
P * T	28 21	—
Total	39 31	

4 RESULTS AND DISCUSSION

4.1 SURVEY OF SOIL DISTURBANCE

The results from the ground survey of disturbance areas are presented in Table 3. Although the two sites were yarded using different skidding patterns, the level of soil disturbance is very similar. The percentages of the cutblock in skid road were 33.5 and 35.0% for the Winnifred and Railroad sites, respectively. The skid road right-of-way was generally classified as a very deep (> 25 cm) disturbance, with the cutslope height often in excess of 1.5 m. Under current legislation, these skid roads would be considered bladed trails and would be fully rehabilitated.

TABLE 3 *Soil disturbance survey results*

Disturbance category	Percent	
	Railroad	*Winnifred*
Undisturbed	62.0	61.0
Very deep disturbance		
Skid road cutslope	8.0	6.5
Skid road running surface	9.0	12.5
Skid road sidecast or berm	18.0	14.5
Total skid road	35.0	33.5
Shallow and deep disturbance	< 1	3.5
Landing and haul road	3.0	2.0

Shallow and deep disturbances on the Winnifred Creek site were dominantly skidtrails (unbladed). It was not recorded if these were compacted, (i.e., considered as heavily used). Landing and haul road areas on both sites were within the 7% recommended in the *Soil Conservation Guidebook* (Province of British Columbia 1995).

4.2 SOIL PHYSICAL PROPERTIES

4.2.1 Soil bulk density

Whole soil bulk density data measured in 1986 with the soil density meter differed significantly at both sites over two depths (Table 4). Bulk densities were highest for the inner track, followed by the outer track, sidecast, and the undisturbed areas. Percentage increases in density were 45% for the inner and 35% for the outer skid road tracks at Winnifred, and 41% for both the inner and outer tracks at Railroad. The observed increase in whole soil bulk densities on the skid road running surface could be attributed to a combination of compaction and increased coarse fragment content in the exposed subsoils (Appendix 1). However, no measures of coarse fragment content could be made using the density meter.

TABLE 4 *Whole soil bulk densities measured with density meter in 1986 at depths of 0–10 cm and 0–30 cm*

	Whole soil bulk density (Mg/m^3)	
Treatment	0–10 cm	0–30 cm
Railroad		
Undisturbed	1.01 a[1]	1.13 a
Inner track	1.36 c	1.59 b
Outer track	1.38 c	1.60 b
Sidecast	1.14 b	1.20 a
Winnifred		
Undisturbed	1.13 a	1.23 ab
Inner track	1.59 c	1.78 d
Outer track	1.54 c	1.66 c
Sidecast	1.25 b	1.31 b

[1] Values in columns followed by same letter are not significantly different at $p < 0.05$.

Fine fraction density (< 2 mm) was estimated from the values in Table 4 using the coarse fragment estimates obtained during soil nutrient sampling and soil descriptions (Table 2 and Appendix 2, and other data not presented). Fine soil densities on the road running surface are estimated to be in the range of 1.15 and 0.55 Mg/m^3 at Winnifred and Railroad, respectively. Fine soil densities on the undisturbed and sidecast positions are estimated as approximately 0.85–0.90 and 0.25–0.40 Mg/m^3, at Winnifred and Railroad, respectively. The sidecast of the skid road was only slightly more dense than the undisturbed soil and did not appear to present a physical limitation to future tree growth.

Whole soil bulk densities at year 11, measured using the excavation method, are similar to those of year 0 on the treatments sampled (Table 5). Because of the different methods used in the 2 years, and different sampling strategies, no statistical comparisons between the 2 years were made.

TABLE 5 *Soil bulk densities measured in 1997 in the mineral soil 0–20 cm layer*

	Soil bulk densities (Mg/m^3)	
Treatment	Fine fraction	Whole soil
Railroad		
Undisturbed	0.26 b[1]	1.27 b
Inner track	0.52 a	1.59 a
Outer track	0.38 ab	1.44 ab
Winnifred		
Undisturbed	0.77 c	1.09 c
Inner track	1.24 a	1.64 a
Outer track	0.97 b	1.46 b

[1] Values in columns followed by same letter are not significantly different at $p < 0.05$.

At first glance, the increases in whole soil density caused by the skid road construction and use easily exceeded the 15% increase commonly used as a definition of a degraded soil (Powers et al. 1998). However, other work has suggested that thresholds in soil density may have to be exceeded before growth is limited (Greacan and Sands 1980; Gale et al. 1991; Burger and Kelting 1999). Although the whole soil densities are high, the fine soil densities at time of plantation establishment appear to be well below the suggested thresholds of 1.6–1.7 Mg/m^3 for sandy soils (Daddow and Warrington 1983).

At Winnifred, fine fraction bulk density of the undisturbed and outer track treatments is less than 1.0 Mg/m^3, and only the density in the inner track treatments appears to be approaching possible threshold values. All mineral soil fine fraction bulk densities at Railroad are very low (< 0.60 Mg/m^3) for mineral soils. The values for fine fraction bulk density are much lower than those normally observed in the Kamloops region, or elsewhere in British Columbia. The low values are due to a combination of two factors observed on-site. First, the mineral soils are relatively high in organic matter (see Table 7). Second, because of the very high coarse fragment content in the soil (see Appendix 1), there are large interstices in the whole soil matrix that are only partially occupied by fine soil.

The fine fraction bulk densities measured at year 11 are very similar to those estimated in year 0. This indicates that fine fraction soil densities were low throughout the life of the plantation and probably have not limited root growth during this time, except in the inner track position at Winnifred Creek. The data also indicate that there has been little natural amelioration of any compaction over the 10-year period.

4.2.2 Soil porosities and moisture

Other soil physical property data measured at year 0 are presented in Table 6. Both total porosity and aeration porosity on the skid road running surface positions were reduced by a large proportion, although not always significantly, compared to the undisturbed soil. Both measures of porosity on the sidecast soil were comparable to the undisturbed position. Available water storage capacity was reduced at the Winnifred site, but not at the Railroad site.

TABLE 6 *Soil porosities and available soil water in the 0–10 cm mineral soil layer in 1986 (all values expressed as percentages)*

Treatment	Total porosity	Aeration porosity	Available water storage
Railroad			
Undisturbed	57 (3.4)[1]	31.0 ab[2] (5.4)	14.7 (7.2)
Inner track	45 (3.5)	20.0 b (9.9)	15.1 (7.1)
Outer track	43 (7.8)	21.0 b (10.6)	12.3 (4.9)
Sidecast	55 (3.1)	34.0 a (5.0)	12.9 (2.5)
Winnifred			
Undisturbed	55 (2.9)	31.7 a (5.4)	16.3 ab (3.0)
Inner track	38 (2.7)	17.6 b (7.1)	11.4 b (3.8)
Outer track	39 (4.1)	14.9 b (7.1)	14.0 ab (5.8)
Sidecast	50 (2.0)	28.2 a (4.5)	12.5 ab (4.8)

[1] Standard deviations are shown in parentheses.

[2] Values in columns followed by the same, or no, letter are not significantly different at $p < 0.1$.

The changes in total porosity may be due to compaction or because some of the porous, more organic-rich topsoil has been displaced from the skid roads compared to the undisturbed or sidecast positions. Reductions in total porosity are not considered to affect tree growth as significantly as changes in aeration porosity and pore size distribution (Childs et al. 1989). A threshold in aeration porosity, similar to the threshold in bulk density, seems to occur, below which root growth may be limited. This limit is generally thought to be in the 10–15% range (Greacan and Sands 1980; Powers et al. 1998). The top end of this range is approached on the coarse soils of this study. Because both sites are well drained, and saturated soil conditions are unlikely to persist for lengthy periods during the growing season, the data do not indicate that low soil aeration will limit root and tree growth.

Available water storage capacity, on a whole soil basis, is a measure of water available for plant growth. This capacity was significantly altered compared to undisturbed areas only at Winnifred ($p < 0.1$) (Table 6). At Winnifred, it was reduced significantly on the inner track only, non-significantly on the outer track and sidecast. At Railroad, available water storage capacity was reduced, though not significantly, on the outer track and sidecast only. Because water storage capacity is primarily a function of the medium-sized pores in a soil, decreasing large pore space (macroporosity) may increase this capacity, leading to an increase in tree growth in sandy soils (Powers et al. 1998). This has not happened on the stony, sandy soils of the present study.

Volumetric soil moisture contents throughout the growing season of 1997 are shown in Figure 1. Because of the small sample size and large variability in moisture contents (data not presented), no statistical analysis was done on the data. At the Winnifred site, moisture content was generally greater at the inner track position, followed by the undisturbed, sidecast, and outer track positions. No obvious pattern was evident in the treatments at Railroad.

The inner and outer track moisture contents could be expected to be greater than the undisturbed and sidecast positions because of possible alteration of slope hydrology as well as a reduction of slope gradient on the skid road surface compared to the undisturbed slope. The data, however, do not support this hypothesis. Reduced water storage capacity of the exposed subsoil material in the track positions may have compensated for the changes in hydrology and slope.

Root growth is limited at high soil moisture contents by soil aeration and at low moisture contents by mechanical resistance properties (da Silva et al. 1994). In sandy, well-drained soils, moisture contents that are sufficient to limit air-filled porosities below 10% are seldom reached at densities below 1.70 Mg/m^3 (da Silva et al. 1994). In addition, the moisture content data in the present study indicate that the soils will rarely be dry enough for soil strength to limit tree growth on the skid roads.

4.3 SOIL CHEMICAL PROPERTIES

Some initial mineral chemical properties varied considerably between the road and the undisturbed areas (Tables 7 and 8). Chemical properties with consistently higher concentrations in the undisturbed areas included total nitrogen, total carbon,

TABLE 7 *Mineral soil chemical properties sampled in 1986 from the 0–20 cm layer*

Chemical property	**Undisturbed**	**Inner track**	**Outer track**	**Sidecast**
Railroad				
Total N (g/kg)	3.2 (0.4)[1] a[2]	0.9 (0.1) b	1.4 (0.1) b	1.4 (0.2) b
Total C (g/kg)	76 (12) a	31 (5) b	51 (6) b	36 (4) b
C:N ratio	22.6 (0.8) c	31.5 (2.2) ab	35.8 (2.3) a	28.0 (1.9) b
CEC (cmol/kg)	30.0 (2.5) a	15.5 (6.2) b	18.7 (0.9) b	18.0 (1.2) b
pH	4.5 (0.1) b	5.1 (0.1) a	5.0 (0.1) a	5.0 (0.1) a
Extractable Ca (mg/kg)	1229 (135)	1177 (120)	1346 (104)	1172 (134)
Extractable K (mg/kg)	111 (8)	59 (10)	109 (8)	113 (8)
Extractable Mg (mg/kg)	144 (11)	186 (15)	175 (9)	174 (12)
Available P (mg/kg)	42 (9)	28 (5)	42 (6)	44 (6)
Winnifred				
Total N (g/kg)	0.4 (0.06) a	0.2 (0.02) b	0.2 (0.03) b	0.3 (0.03) b
Total C (g/kg)	12.8 (0.9) a	6.6 (1.1) b	8.0 (0.9) b	9.2 (1.4) b
C:N ratio	33.2 (1.3) a	31.5 (1.8)	37.1 (2.1)	32.2 (1.7)
CEC (cmol/kg)	6.5 (0.3)	5.6 (0.4) b	5.3 (0.3) b	5.4 (0.3) b
pH	4.9 (0.05) c	5.5 (0.07) a	5.4 (0.06) a	5.2 (0.06) b
Extractable Ca (mg/kg)	314 (27) c	647 (70) a	537 (34) ab	478 (38) b
Extractable K (mg/kg)	70 (4)	57 (4)	61 (5)	60 (4)
Extractable Mg (mg/kg)	31 (3) c	78 (10) a	62 (5) b	57 (5) b
Available P (mg/kg)	96 (7) a	37 (6) c	44 (6) bc	61 (8) b

1 Standard errors of the mean given in parentheses.

2 Values in rows followed by the same letter, or without letters, are not significantly different at $p < 0.05$.

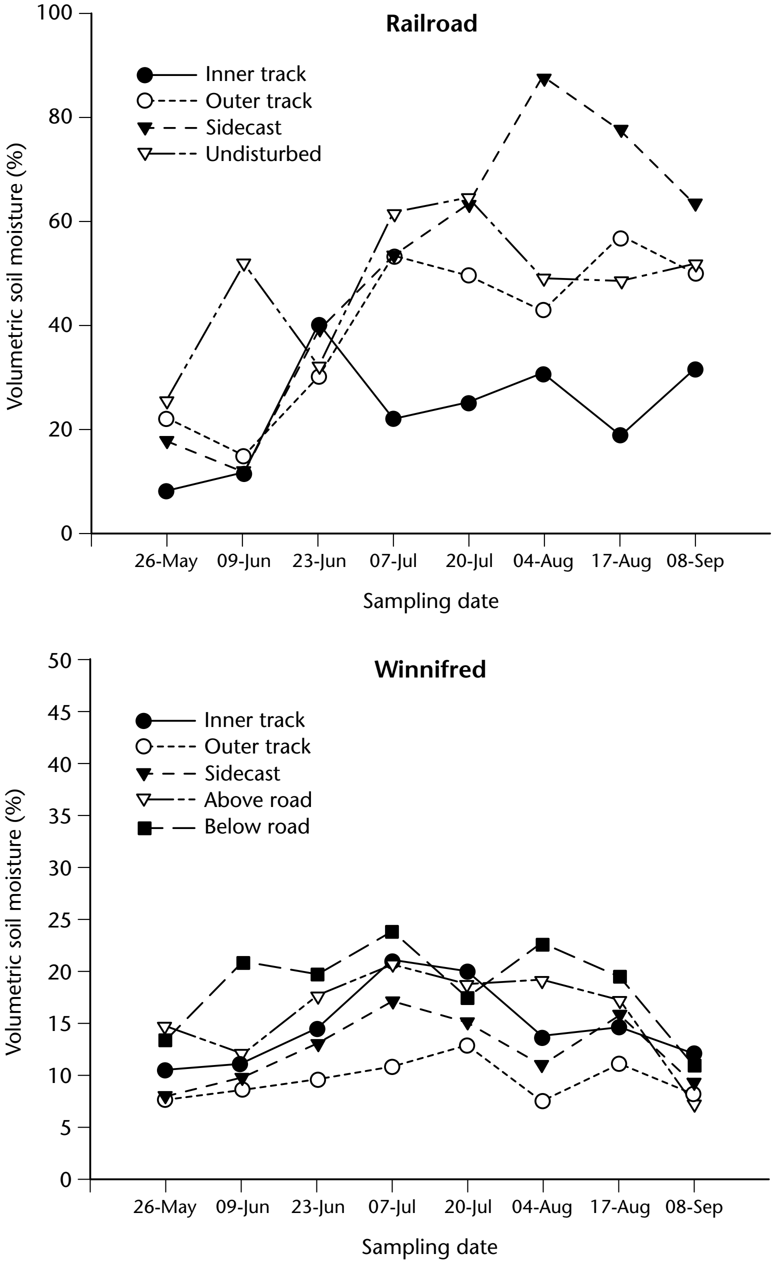

FIGURE 1 *Volumetric soil moisture content (%) throughout the 1987 growing season at the two study sites.*

and CEC. Soil pH was consistently lower on the undisturbed areas than on the road treatments. The effects of disturbance on extractable cation (calcium, magnesium, and potassium) concentrations were less consistent. Extractable cation and phosphorus concentrations were generally at moderate to high levels on all treatments. Chemical property concentrations that are largely affected by organic matter (N, C, CEC) were lowered by the skid road construction, whereas those more affected by pH (the cations and P) were variably affected by the exposure of more alkaline subsoil material. Mineral soil chemical content was not calculated because both coarse fragment content and fine fraction bulk densities were not determined during soil sampling.

The chemical contents of the forest floor, in kilograms per hectare (Table 8), represent those amounts potentially lost from the inner and outer track positions by displacement during skid road construction. On the steep slopes of the present study and with the blade construction methods used, it is probable that some of the displaced material would be included in the fill on which the outer track is partially constructed. Some forest floor mixed with mineral soil would definitely be part of the sidecast material sampled as mineral soil.

TABLE 8 *Forest floor chemical concentrations and contents sampled in 1986*

Element	**Railroad**	**Winnifred**
	Total chemical concentration (g/kg)	
N	5.6 (0.03)[1]	5.6 (0.03)
P	1.1 (0.004)	0.6 (0.002)
Ca	14.0 (0.12)	4.9 (0.02)
K	0.6 (0.004)	0.6 (0.002)
Mg	3.4 (0.04)	0.9 (0.003)
	Total chemical content (kg/ha)	
N	1102	309
P	93	31
Ca	1285	275
K	56	37
Mg	307	52

[1] Standard errors of the mean in parentheses.

Concentrations of nitrogen, generally assumed to be a common limiting nutrient in the interior, are comparable to other undisturbed soils in the ICH zone in all treatments at Railroad. At Winnifred, nitrogen levels are low, although adequate growth has been observed on other sites in the Kamloops Forest Region with similar low soil nitrogen levels (G.D. Hope, unpublished data). Total nitrogen concentrations may indicate the potential of the soil to supply nitrogen over the long term, but in the short term, N availability indexes more sensitive to nitrogen cycle dynamics would be required to assess availability (Binkley 1986). Other properties (P, cations, and pH) seem adequate on both sites to support tree growth at acceptable interior rates. Cation availability, in fact, rarely limits tree growth (Binkley 1986) because of the ability of soil minerals to replace any cations lost during forestry operations.

As discussed previously, the concept of a threshold above (or in some cases, below) which tree growth may not be affected is also valid for nutrients. For example, Gale et al. (1991) suggest that the optimum pH for white spruce is between 5.0 and 7.0. Threshold sufficiency curves have not been published for the majority of nutrients, species, and climates of this study. However, because availability of many nutrients also depends on other physical chemical properties (e.g., soil temperature and soil moisture), predicting adequate levels for many of the chemical properties is difficult.

Although considerable amounts of organic-rich forest floor and topsoil has been lost from the inner and outer track positions, it is not known if the amounts remaining are sufficient to sustain growth over the medium or longer term. The impact of the lower nutrient pool in the 0–20 cm layer will not be of major consequence in the sidecast or berm because the organic pool buried under the deposited material eventually becomes accessible to the maturing regeneration.

4.4 FOLIAR NUTRIENT CONCENTRATION

Statistically significant differences ($p < .05$) in foliar nutrient concentrations were observed in some instances (Table 9). Some other nutrient elements that were measured, namely copper, zinc, and active iron, for which nutrient concentrations were well above adequate levels and no significant differences between treatments were observed, are not reported here.

TABLE 9 *Selected foliar nutrient concentrations in 5-year-old trees*

Parameter	Species[1]	Undisturbed	Inner track	Outer track	Sidecast	Adequate level[2]
Railroad						
Mass[3] (g)	Pl	1.08 c[4]	1.48 b	1.85 a	1.49 b	n/a
	Sx	0.16 b	0.17 b	0.20 a	0.17 b	n/a
N (g/kg)	Pl	16.2	17.2	17.2	17.3	13.5
	Sx	13.3	13.5	14.1	14.5	14.5
P (g/kg)	Pl	1.8 b	1.9 ab	2.0 a	2.0 a	1.5
	Sx	2.7 b	2.7 b	2.9 ab	3.0 a	1.6
K (g/kg)	Pl	7.1	7.0	7.4	7.9 a	5.5
	Sx	6.9	6.7	6.9	7.2	5.0
Mg (g/kg)	Pl	1.1	1.1	1.1	1.0	1.0
	Sx	1.2	1.2	1.2	1.1	1.2
Ca (g/kg)	Pl	1.7	1.9	1.8	1.9	1.0
	Sx	3.7	4.0	4.1	3.7	1.5
S (g/kg)	Pl	1.2	1.3	1.3	1.4	1.2
	Sx	1.1	1.2	1.1	1.1	1.2
B (mg/kg)	Pl	8.0 b	8.9 b	10.6 ab	12.5 a	12
	Sx	5.9 b	7.0 b	11.8 a	7.7 b	12
Mn (mg/kg)	Pl	169 b	182 b	227 a	177 b	25
	Sx	197	278	224	204	25
Winnifred						
Mass[3] (g)	Pl	1.58 b	1.72 ab	2.13 a	1.96 a	n/a
	Fd	0.26 a	0.26 a	0.26	0.28	n/a
N (g/kg)	Pl	15.6	15.6	15.4	16.2	13.5
	Fd	11.2	11.9	11.9	11.5	13.5
P (g/kg)	Pl	1.6	1.7	1.7	1.7	1.5
	Fd	1.9	2.1	1.9	2.0	1.5
K (g/kg)	Pl	7.3 b	7.4 ab	7.7 ab	7.9 a	5.5
	Fd	7.8	7.5	7.5	7.9	6.5
Mg (g/kg)	Pl	1.1	1.2	1.1	1.1	1.0
	Fd	1.1	1.1	1.1	1.2	1.2
Ca (g/kg)	Pl	2.0 ab	2.4 a	2.1 ab	1.9 b	1.0
	Fd	2.3	2.4	2.4	2.7	2.5
S (g/kg)	Pl	1.0	1.0	1.0	1.1	1.2
	Fd	0.95	0.90	0.95	1.00	1.2
B (mg/kg)	Pl	12.1	10.5	11.3	14.3	12
	Fd	7.6	6.9	8.9	9.9	12
Mn (mg/kg)	Pl	226	329	337	250	25
	Fd	254	324	328	300	25

[1] Pl = lodgepole pine; Sx = white spruce; Fd = Douglas-fir.

[2] Ballard and Carter (1986).

[3] Needle mass per 100 needles for Sx and Fd, per 75 pairs for Pl.

[4] Values in rows followed by the same letter, or without letters, are not significantly different at $p < 0.05$.

The differences in mean foliar levels generally parallel those seen in seedling growth data. Foliar nutrient level and needle mass are predominantly highest in the sidecast or outer track positions. Because the needle mass was significantly higher in the three skid road positions relative to the undisturbed location, for pine at both sites and spruce at the Railroad site, nutrient content (on a milligram per needle basis) would often also be significantly different for many nutrients. However, this does not imply changes in nutrient deficiency status; it is more likely that the nutrients are non-limiting (Ballard and Carter 1986).

Where statistical differences between treatments were observed, foliar nutrient levels are generally still adequate for all treatments (Ballard and Carter 1986), and the differences are unlikely to affect growth. Elements that may be inadequate for optimum growth are: nitrogen, in spruce at Railroad and Douglas-fir at Winnifred, in all treatments; boron (B), in both species on some treatments at Railroad, and in Douglas-fir on all treatments at Winnifred; and sulphur (S), in Douglas-fir on all treatments at Winnifred. Where foliar levels are inadequate on all treatments, nutrition does not explain any growth differences. Adequate levels in the large majority of nutrients in all species also indicate that nutrition does not appear to be the dominant growth-limiting factor on any treatment.

4.5 SEEDLING GROWTH

The 10-year survival data from both locations (Table 10) indicate reasonable survival (> 80% at Railroad, > 70% at Winnifred) on all treatments for both species. At Railroad, no significant differences were evident between treatments ($p < 0.1$) for both species, although survival was consistently highest on the outer track position. At Winnifred, a trend of lower survival on the inner track and undisturbed areas for both species was observed, but the differences were significant only for lodgepole pine.

Survival decreased slowly and steadily over the 10-year period on all treatments and with no marked differences in survival between any time period. Survival tended to decrease slightly, but not significantly, between years 5 and 10, on both sites. Occasional cutslope slumps were the most common cause of mortality on both sites between years 5 and 10. These

TABLE 10 *Percent survival of planted trees after 10 years*

	Railroad		*Winnifred*	
Treatment	**Lodgepole pine**	**White spruce**	**Lodgepole pine**	**Douglas-fir**
Undisturbed–above	86	84	74 b[1]	86
Undisturbed–below	—	—	69 b	79
Inner track	86	89	72 b	69
Outer track	93	94	91 a	89
Sidecast	79	89	89 a	90

[1] Values in columns followed by the same letter, or without letters, are not significantly different at $p < 0.05$

slumps most affected the inner track position at Winnifred and the lower row of the undisturbed plots above the skid road at Railroad. All treatments were affected to some extent. Cutslope slumps were smaller in area at Winnifred and often only affected the inner track position. On the steep Railroad site, slumps included the entire cutslope and often cut back into the undisturbed rows above the road.

At Railroad, a high proportion of trees on all treatments had broken branches on the up-slope side of the tree, and broken or bent stems. Lodgepole pine suffered more severe damage than the spruce. This damage appears to be caused by snow creep on the very steep, north-facing slopes.

Multiple analysis of variance (MANOVA) of the height versus time curves shown in Figure 2 (analysis summaries are given in Appendix 2) indicated that the rates of height growth over the 10-year period were significantly different ($p < 0.05$) on the different treatments for all species. Therefore, skid road position significantly affected height and stem diameter growth over the 10-year period (i.e., the growth curves are not parallel).

One-way ANOVA tests indicated significant growth differences at year 10 (Table 11). All measures of growth generally indicated that growth on the outer track and sidecast positions was significantly greater than that on the inner track and undisturbed locations. Growth on the inner track was equal to, or exceeded, that on the undisturbed locations. These trends were the same for all three species, although the location of the largest trees was on the sidecast at Winnifred, and the outer track at Railroad. At Winnifred, growth on the lower undisturbed position was greater than that on the undisturbed

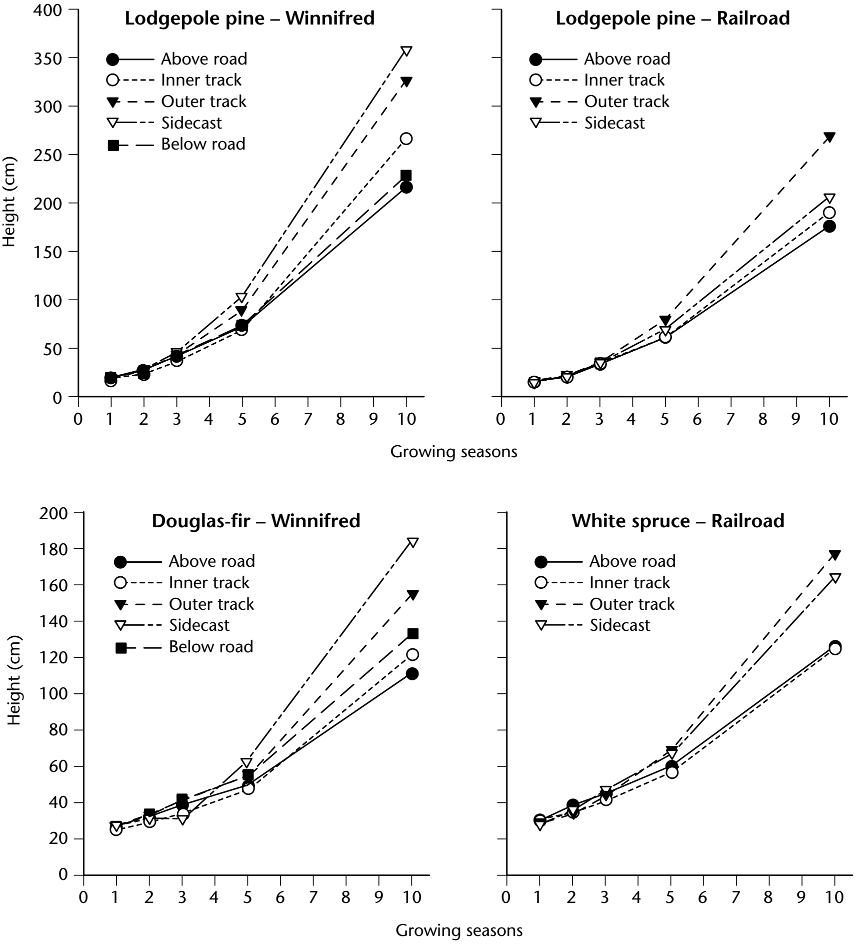

FIGURE 2 *Mean height of planted species one (1987) to 10 (1996) growing seasons after planting at the two study sites.*

locations above the road, although the differences are usually not significant.

Growth differences were not exhibited until at least year 3. Diameter differences among treatments appeared earlier than did height differences (data not shown). Growth differences, both height and diameter, that were apparent at year 5 usually maintained their relative rankings at year 10. The one exception was where the inner-track trees at both sites were smaller

TABLE 11 *Growth measurements 10 growing seasons after planting*

	Height (cm)	Stem diameter (cm)	Stem volume (cm^3)[1]	Height (cm)	Stem diameter (cm)	Stem volume (cm^3)
Railroad	**Pine**			**Spruce**		
Undisturbed –above	179 b[2] (11)[3]	3.6 b (0.28)	607	126 b (6)	2.6 b (0.17)	223
Inner track	191 b (13)	4.5 b (0.26)	1012	125 b (5)	2.9 b (0.10)	275
Outer track	269 a (17)	6.3 a (0.40)	2793	177 a (9)	4.1 a (0.13)	778
Sidecast	205 b (11)	4.5 b (0.37)	1086	164 a (9)	3.6 a (0.24)	556
Winnifred	**Pine**			**Douglas-fir**		
Undisturbed –above	218 c (14)	3.6 d (0.20)	739	112 d (8)	2.2 b (0.14)	142
Inner track	266 b (20)	4.4 c (0.30)	1348	122 c (5)	2.5 b (0.13)	200
Outer track	328 a (16)	5.3 b (0.20)	2410	155 b (10)	3.0 a (0.14)	365
Sidecast	359 a (12)	6.3 a (0.30)	3728	183 a (13)	3.4 a (0.18)	554
Undisturbed –lower	229 c (12)	3.5 d (0.20)	734	133 c (9)	2.4 b (0.19)	200

[1] Stem volumes are presented for information only without statistical analysis.

[2] Numbers within a column followed by different letters are significantly different at $p < 0.05$.

[3] Standard errors of the mean in parentheses.

on average than trees on undisturbed positions at year 5 and then grew more rapidly between years 5 and 10 than the undisturbed-position trees.

One-way ANOVA using both sites combined for lodgepole pine, followed by multiple comparisons (data not shown) indicated no statistical difference between growth on the outer track and sidecast treatments. Growth on the inner track was significantly less than the other two road treatments, but was significantly greater than the undisturbed position above the road. Height and diameter of trees in the outer track and sidecast positions were approximately 35 and 55%, respectively, greater than those in the undisturbed positions. On the inner track, height and diameter were 8 and 25%, respectively, greater than those in the undisturbed positions. On these coarse soils in this biogeoclimatic zone, the conditions created by skid road soil disturbance appear to enhance short-term lodgepole pine growth.

Reductions in soil chemical properties and increases in soil densities on the track positions appear to be insufficient to reduce growth. This supports the idea that threshold values in these soil properties have not been reached on these low-sensitivity soils.

If water storage capacity and water content have not increased, and if aeration porosity, soil strength, and nutrition are not limiting growth, then the increased growth on the outer track and sidecast positions is most likely due to a favourable change in some other growth-limiting factor not determined in the present study. The most likely causes of increased growth on the roads relative to the undisturbed areas are lack of vegetation competition, either above- or below-ground (Smith and Wass 1976), and accelerated soil warming resulting from the removal of the organic horizon (Fleming et al. 1998).

After 10 years of growth, the changes in soil physical and chemical properties associated with skid road construction on these two sites appear not to have negatively affected tree growth. However, altered slope stability and subsurface flow, reflected by the ongoing mass wasting associated with the constructed skid roads, indicates that overall site productivity may be affected.

5 CONCLUSIONS

Approximately one-third of each of the steep slope study areas is occupied by soil disturbances associated with construction and use of bladed skid roads.

Whole soil bulk densities were increased by approximately 40% on the skid road surfaces. Although large relative increases occurred in fine fraction bulk densities, these densities did not approach apparent growth-limiting thresholds, except on the inner track at Winnifred Creek. Any effects of skid road soil disturbances in this study may be attributed to displacement rather than compaction.

Other soil physical properties, such as porosity, aeration, and water storage capacity, were not reduced below apparent threshold values.

Although soil chemical content was reduced by displacement of the forest floor and surface mineral soil, the concentration of chemical parameters remaining may be sufficient to adequately support tree growth.

Tree growth over the 10-year period was greatest on the skid road sidecast and outer trail positions at both sites. Inner track growth was comparable to that of the non-track areas. Foliar nutrient levels did not indicate any possible deficiencies specific to the disturbed areas. Possible deficiencies seemed more related to overall site conditions.

Increases in bulk density, losses of porosity, and changes in nutrient content were still apparent 10 years after the initial measurements. These changes have not ameliorated over the time period.

Both sites have soils best described as very coarse textured (i.e., they are of sandy texture with moderate to high coarse fragment content). These soils are more resistant to compactive forces than finer-textured soils. As well, the soils on the two study sites are well aerated, allow very good root exploitation, and have moderate levels or organic matter and nitrogen even after displacement of more favourable topsoils. It would be ill-advised to generalize and extrapolate these results to soils and ecological conditions outside those of the study areas. Other studies have shown that the site-specific interaction of climate, soils, and management should be considered in understanding long-term effects of soil disturbance (Greacan and Sands 1980; Miller et al. 1996). In addition, 10 years of growth data should not be considered long term. Moreover, longer-term monitoring of plantation performance will be necessary to substantiate this conclusion.

Under the present legislation, bladed trails such as the ones in this study would need to be rehabilitated. The results from this study indicate that rehabilitation of the running surface on these specific sites would require minimal decompaction and topsoil respreading effort to restore soil productivity. Slope recontouring and stabilization would also be necessary, however, to prevent ongoing mass wasting and loss of site productivity.

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APPENDIX 1

Site descriptions

I RAILROAD CREEK

Site
Site series: ICHmw2/01 (transition to ESSFwc2)
Moisture regime: submesic–mesic Nutrient regime: poor
Early seral: Fireweed/Bluejoint reedgrass
Maturing climax: Cw/Falsebox – Feathermoss

Physiography
Slope position meso: upper to lower; slope shape: straight to convex
Aspect: northeast; slope gradient (%): 50–70
Vegetation (clearcut): Early seral
Strata coverage (layer and %): A-0, B-20, C-50, D-0
Dominant species in clearcut (July 1987):

Shrubs:	*Acer glabrum*, *Ribes lacustre*, *Paxistima myrsinites*, *Rubus idaeus*
Herbs:	*Epilobium angustifolium*, *Calamagrostis candensis*, *Clintonia uniflora*, *Tiarella unifoliata*

Soil
Subgroup: Orthic Humo-Ferric Podzol
Humus form: Leptomoder
Drainage: rapid
Restrictive layer depth (cm): none

Parent material
Lithology: Metamorphic
Classification: Colluvial blanket

Profile:

Horizon	Depth (cm)	Description
F	19–16	Loose; very friable; burnt herbaceous fragments; few fine roots.
H	16–0	Strong granular; friable; greasy; abundant fine and very fine roots.
Bf	0–25	Dark brown (7.5 YR 3/4) moist; loamy sand; single grain; loose; 55% gravel and 5% cobbles; abundant coarse and fine roots; gradual wavy boundary.
Bm	25–44	Dark yellowish brown (10 YR 4/4) moist; coarse sand; single grain; loose; nonsticky and nonplastic; 55% gravel and 5% cobble; abundant fine roots; gradual wavy boundary.
BC	44–75+	Yellowish brown (10 YR 5/4) moist; coarse sand; single grain; loose; nonsticky and nonplastic; 75% gravel and 5% cobble; few fine roots.

II WINNIFRED CREEK

Site

Site series: ICHmw2/01 and 02 (transition to ICHmk1)
Moisture regime: subxeric–submesic Nutrient regime: poor
Early seral: Pinegrass
Maturing climax: (Cw) Falsebox - Pinegrass

Physiography

Slope position meso: middle; slope shape: straight to convex
Aspect: south; slope gradient (%): 35–55
Vegetation (clearcut): Early seral
Strata coverage (layer and %) : A-0, B-50, C-70, D-8
Dominant species in clearcut (July 1987)
Shrubs: *Paxistima myrsinites*, *Spirea betulifolia*, *Vaccinium membranaceum*
Herbs: *Calamagrostis rubescens*, *Lupinus articus*, *Hieracium albiflorum*

Soil

Subgroup: Orthic Dystric Burnisol
Humus form: Moder
Drainage: well to rapid
Restrictive layer depth (cm): 55–compact till

Parent Material

Lithology: Granitic
Classification: Colluvial veneer over morainal (compact till) blanket

Profile:

Horizon	Depth (cm)	Description
L	3–2	Loose, herbaceous fragments.
F	2–0	Friable, herbaceous fragments; scats and casts; few yellow mycelia fungi; abundant fine roots.
Bml	0–11	Yellowish brown (10 YR 5/4) moist; loamy sand; weak fine subangular blocky; very friable; nonsticky and nonplastic; 10% gravel; abundant fine roots; abrupt wavy boundary.
Aeb	11–17	Pale brown (10 YR 6/3) moist; loamy sand; single grain; very friable; nonsticky and nonplastic; 10% gravel; abundant fine and a few coarse roots; abrupt wavy boundary.
Bm2	17–54	Light yellowish brown (10 YR 6/4) moist; sand; moderately compact; firm; single grain; nonsticky and nonplastic; 55% gravel and 5% cobble; very few to no roots; gradual wavy boundary.
BC	54–80+	Light brownish grey (10 YR 6/2) moist; sand; massive; moderately compact; very firm; nonsticky and nonplastic; 55% gravel and 5% cobble; very few to no roots.

APPENDIX 2

Summary of univariate and multivariate repeated measures analysis of seedling height versus time curves

Site	Species	F	P values
Univariate test of null hypothesis that curves are parallel			
Railroad	Pl	19.96	0.0001
	Sx	17.88	0.0001
Winnifred	Pl	29.30	0.0001
	Fd	8.96	0.0001
Multivariate test of null hypothesis that curves are parallel (using Wilk's lambda)			
Railroad	Pl	5.62	0.0001
	Sx	5.30	0.0001
Winnifred	Pl	8.59	0.0001
	Fd	3.05	0.0001
Univariate test of null hypothesis that curves are not different			
Railroad	Pl	2012.58	0.0001
	Sx	1618.09	0.0001
Winnifred	Pl	3249.01	0.0001
	Fd	1063.19	0.0001
Univariate test of null hypothesis that curves cancel over time			
Railroad	Pl	2667.45	0.0001
	Sx	1216.78	0.0005
Winnifred	Pl	22.21	0.0001
	Fd	6.18	0.0001