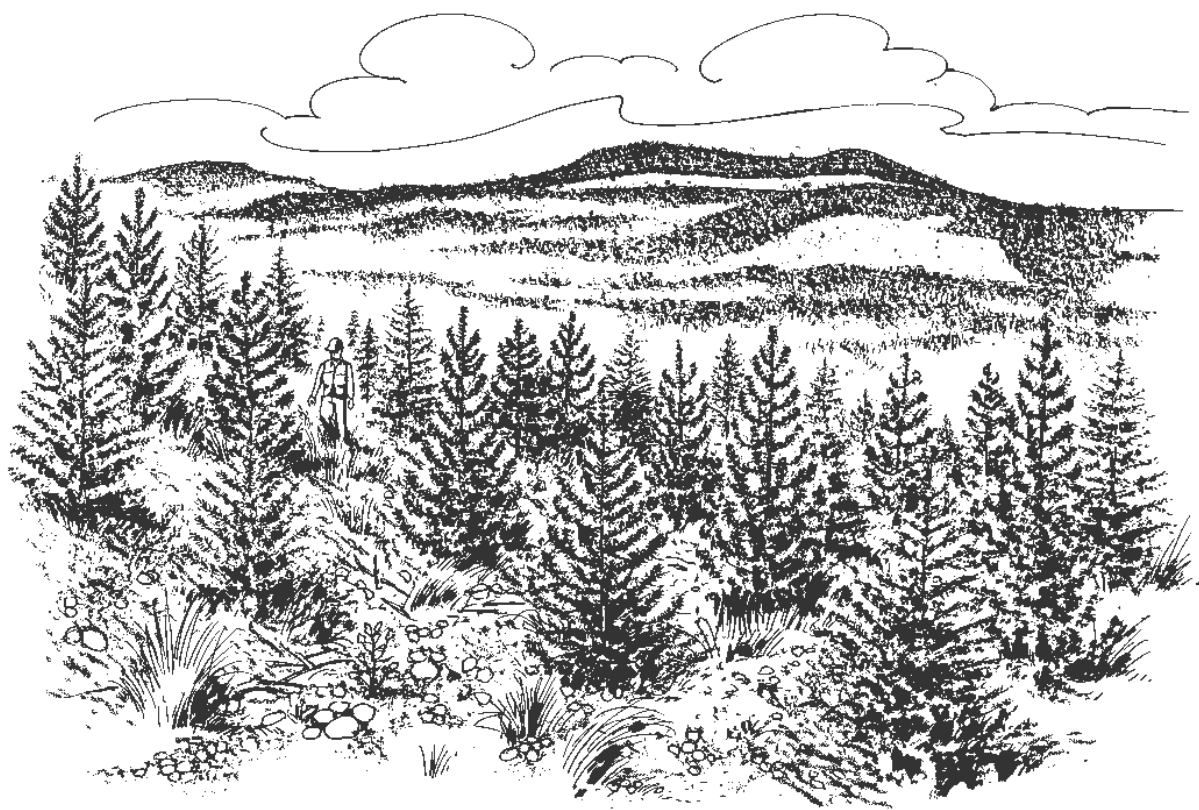




Canadian Forest Service
Effects of Forestry Practices Network

Impacts of cross-contour skidroads on properties of a gravelly sandy loam soil and on planted seedling performance



E. F. Wass and R.B. Smith – Canadian Forest Service

Information Report BC-X-369
Pacific Forestry Centre, Victoria, B.C.



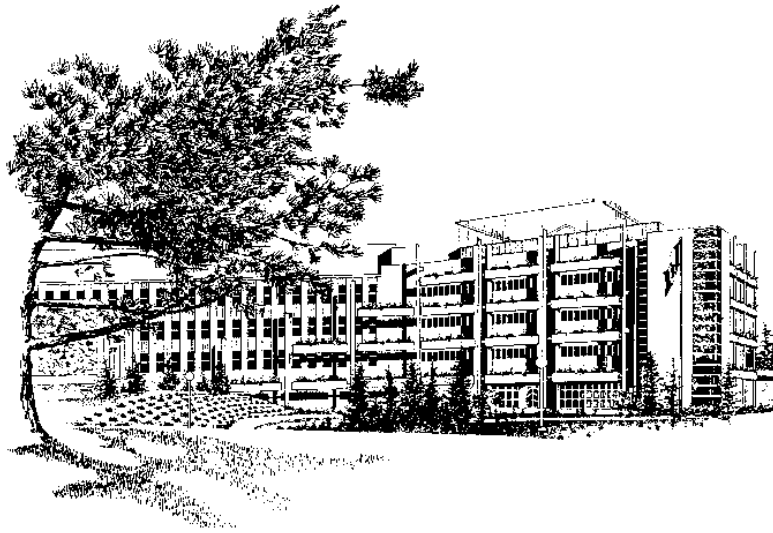
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Pacific Forestry Centre - Information Report BC-X-369

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1997

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Abstract

Soil conditions, growth of 1200 planted seedlings each of lodgepole pine (*Pinus contorta* var. *latifolia*) and Douglas-fir (*Pseudotsuga menziesii*), and development of other vegetation were studied to gauge the effect of skidroads on site productivity of a coarse-textured, cobbly, glacio-fluvial soil in south-central British Columbia. Soil density, penetrability, texture, and chemistry were assessed before planting seedlings. Seedling foliage nutrients and root development were analyzed five growing seasons after planting. To reduce the potential for erosion, the steep, cross-contour skidroads were operationally seeded with a mixture of grasses and legumes. Despite reduced soil quality on skidroad surfaces, including increased density and resistance to penetration and reduced organic matter content and water-holding capacity, tree growth rates after 10 years were generally not significantly different from those on adjacent undisturbed soil. Low vegetative competition on the excavated skidroads relative to undisturbed soil and increased nitrogen from the seeded legumes are suggested as compensatory factors. The survival rate of seedlings was least on berms but those that did survive had generally greater growth rates and root development than those growing in undisturbed soil and, especially, in skidroad surfaces.

Résumé

On a étudié les conditions du sol, la croissance de 1 200 semis de pin tordu latifolié (*Pinus contorta* var. *latifolia*) et de 1 200 semis de douglas vert (*Pseudotsuga menziesii*) et le développement d'autres espèces végétales pour évaluer les effets des chemins de débardage sur la productivité de stations à sol pierreux et à texture grossière, composé de dépôts fluvio-glaciaires, dans le centre-sud de la Colombie-Britannique. Avant la plantation des semis, on a évalué la densité du sol, sa pénétrabilité, sa texture et ses propriétés chimiques. On a analysé la teneur en éléments nutritifs du feuillage des semis et le développement de leurs racines cinq saisons de végétation après la plantation. Pour réduire les risques d'érosion, on a ensemencé les chemins de débardage abrupts établis transversalement aux courbes de niveaux avec un mélange de graminées et de légumineuses lors des opérations de plantation. Malgré une diminution de la qualité du sol des chemins de débardage, y compris une augmentation de la densité et de la résistance à la pénétration et une réduction de la teneur en matière organique et de la capacité de rétention d'eau, les taux de croissance des arbres, après 10 ans, n'étaient généralement très différents de ceux établis dans le sol adjacent non perturbé. On pense que la faible concurrence végétale régnant dans les chemins de débardage perturbés par les travaux de terrassement et le surcroît d'azote provenant des légumineuses auraient agi comme facteurs de compensation. Les semis plantés sur les accotements présentaient le taux de survie le plus faible, mais ceux qui y ont prospéré avaient généralement un taux de croissance et un développement racinaire supérieurs à ceux établis dans le sol non perturbé et, notamment à ceux poussant dans les anciens chemins de débardage.

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1.0 Introduction

Effects of forestry operations on soils are a serious concern in British Columbia (B.C.), particularly in mountainous regions. Utzig and Walmsley (1988) estimated that soil degradation from forestry operations reduced annual wood yield over a 10-year period (1976-1985/86) an estimated 400 000 m³, and that this amount was increasing by about 50 000 m³ each year. Lousier (1990) concluded from the literature that “compaction-induced” volume reductions over the entire harvest area (cutblock) were in the range of 10-15%. The severity of impact depends on the type and degree of disturbance and on soil and site factors. Smith and Wass (1979) found that in the Engelmann Spruce-Subalpine Fir Zone, tree growth was particularly reduced on skidroads constructed in medium-to-fine textured soil derived from alkaline parent material. On these soils, reductions in site productivity based on reduced height growth and as prorated over whole cutblocks were estimated to be as much as 15% for subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and 12% for Engelmann spruce (*Picea engelmannii* Parry). In another study on calcareous soils in the lower-elevation Interior Cedar Hemlock Zone, Smith and Wass (1994a) found overall reduced productivity resulting from skidroad construction and use of 4% for Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) and 5% for lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.). Growth on skidroads was also reduced on strongly acid, coarse-textured soil developed under a wet climatic regime with prorated productivity reductions ranging from 2.1 to 14.5% (Smith and Wass 1980)¹. In contrast, skidroad disturbance on moderately coarse, acid soils on cool aspects had beneficial effects on tree growth (Smith and Wass 1979)².

An opportunity to study the changes in soil characteristics and in site productivity resulting from the construction and use of cross-contour (downhill) skidroads in a soil texture/climatic zone combination not previously studied arose in 1983 when a stand north of Clearwater, British Columbia, was harvested. The British Columbia Ministry of Forests (BCMOF) recognized that severe soil disturbance had been caused by the deep, steeply sloping skidroads and were concerned about post-logging soil erosion, future productivity loss, and public reaction to the clearcut, which was clearly visible from a major highway. To reduce the potential for soil erosion, the BCMOF seeded the skidroads with grasses and legumes (creeping red fescue (*Festuca rubra* L.), Kentucky bluegrass (*Poa pratensis* L.), S.C. red clover (*Trifolium pratense* L.), Alsike clover (*Trifolium hybridum* L.), annual ryegrass (*Lolium temulentum* L.), and white Dutch clover (*Trifolium repens* L.)). The Canadian Forest Service was asked to determine effects of the skidroads on site productivity.

The main objectives of our study were to describe the effects of the constructed skidroads on soils, on vegetation composition and development of vegetation, and on the growth of planted trees. The hypothesis was that the effects 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. The seeding of grasses and legumes introduced a complication to assessment of the results, but also an opportunity to determine its effect on vegetation cover and composition.

¹ See Vunder Fire, p. 21.

² See Templeton Creek, p. 14-16.

2.0 Study Area

2.1 Ecology and soils

The cutblock (FL A18694, Blk. F, CP 38) is located in the Thompson Moist Warm variant of the Interior Douglas-fir Zone (IDFmw2) (Lloyd et al. 1990), approximately 40 km east of Clearwater, British Columbia. The average elevation of the site is 853 m, and the aspect is south. The original stand was composed of Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco) (60%) and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) (40%). Based on topography, the cutblock was divided into two sections (Figure 1). The lower section is gently to moderately sloping (10-47%) and dominated by plant association *Pseudotsuga menziesii* -*Thuja plicata*-*Paxistima myrsinites*-*Chimaphila umbellata* (Lloyd et al. 1990). The upper section is steeply sloping (30-70%) and is dominated by the plant association *Pseudotsuga menziesii*-*Calamagrostis rubescens*-*Pleurozium schreberi* (Lloyd et al. 1990). The soils are cobbly sandy loams to loamy sands derived from glacio-fluvial deposits.

2.2 Skidroads

The skidroads were oriented across the contour; i.e., with a definite downhill bias. Those from the lower section of the cutblock had cutbanks averaging 0.6 m in depth, with an average horizontal distance from the top of the cutbank to the bottom of the sidecast of 8.4 m. This was composed of a cutbank (1.1 m), running surface (4.4 m), and berm and sidecast (2.9 m). Skidroads in the upper section of the cutblock had cutbanks averaging 0.6 m in depth, with an average horizontal distance from the top of the cutbank to the bottom of the sidecast of 8.9 m. This was composed of a cutbank (1.4 m), running surface (4.5 m), and berm and sidecast (3.0 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) conducted along a system of transects located and oriented as recommended by Bloomberg et al. (1980). Soil disturbance was classified by cause as deposits or gouges and by three depth classes (<5 cm, 5-25 cm, and >25 cm) or as undisturbed. A total of 389 points were surveyed and described. Similarly, data were gathered from 101 points on transects in an adjacent unlogged stand (Figure 1).

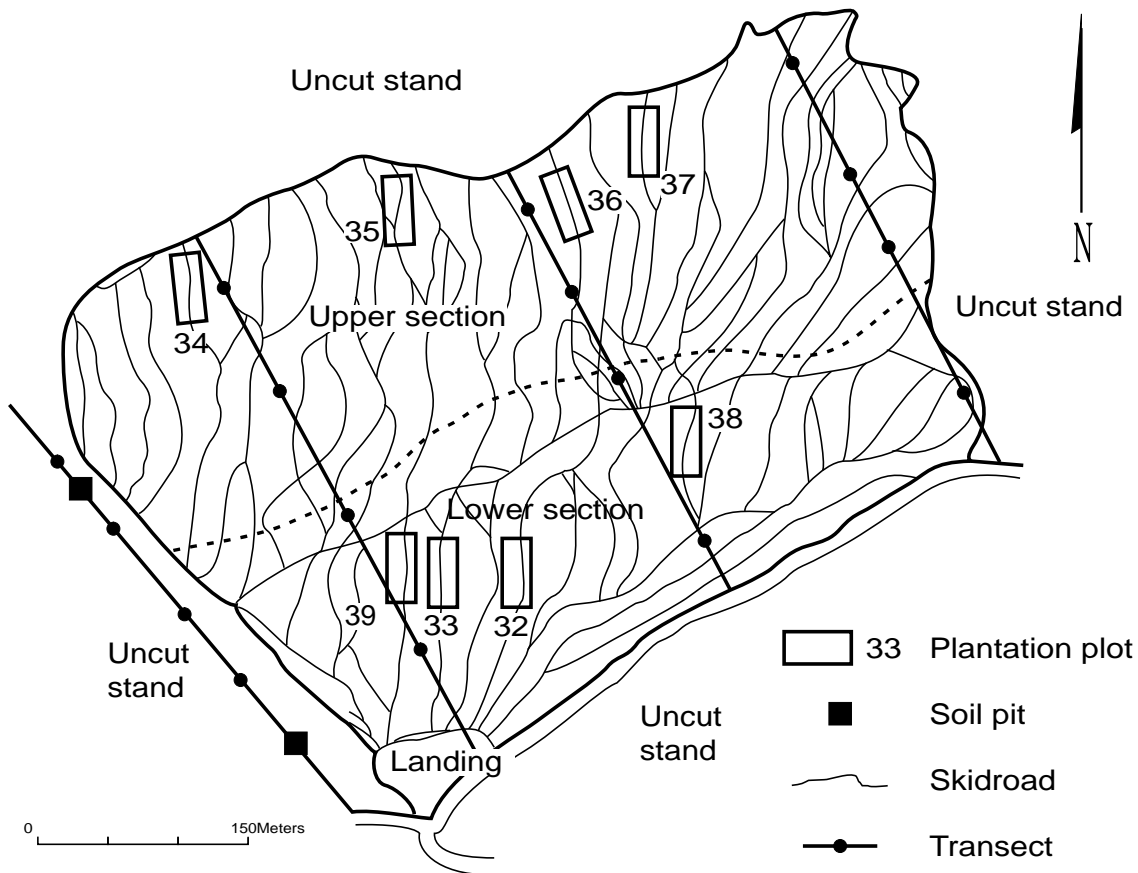


Figure 1. Map of Clearwater study area

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). One sample was taken at each of two depths (0-10 cm and 10-20 cm) in each of three categories in each of eight plantation plots. The categories were the skidroad surface, berm, and undisturbed mineral soil. Bulk densities were calculated for total soil and for the fraction made up of particles less than 2 mm in diameter (the fine fraction).

3.2.2 Penetrability. Penetrability was measured with a U.S. Corps of Engineers Model CN-973 penetrometer equipped with a 1.3 cm² cone. Four probes were made to a depth of 20 cm at each of the bulk density sites situated in the skidroad surface and berm in each of the eight plots. After removing any humus, four probes were made at each of the bulk density sites situated in the undisturbed mineral soil in each of the eight plots.

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 soil fraction of bulk density samples was analyzed for the following characteristics:

1. pH- potentiometrically in 0.01 M CaCl₂ (McMullan 1971).
2. organic carbon- LECO induction furnace (McKeague 1978).
3. total nitrogen- automated semi-micro Kjeldahl (McKeague 1978).

3.2.5 Soil profiles. Two soil pits were described, sampled and classified (Walmsley et al. 1980; Agriculture Canada Expert Committee on Soil Survey 1987). Both pits were located in the unlogged stand adjacent to the study area: one in the lower section and another in the upper section (Figure 1). Samples taken from the centre of soil horizons were sieved, the coarse fragments weighed, textures of the fine fraction determined, and tests made for total nitrogen, pH, and organic carbon.

3.3 Plantations

3.3.1 Layout. Eight plots (four plots in each section) approximately 10 x 50 m in size were established, each straddling discrete skidroad sections and including undisturbed ground on both sides of the skidroads (Figure 1). The plantation plots on the upper section had an average slope of 65% and the skidroads had an average grade of 54%. These skidroad sections had a normal cutbank, skidroad surface, berm, and sidecast configuration (Figures 2A and 3A). Plantation plots and skidroads on the lower section had an average slope or grade of 34%. The skidroad sections had berms on each side of the skidroad surface, which tended to obscure the cutbanks (Figures 2B and 3B).

One hundred and fifty seedlings each of Douglas-fir and lodgepole pine were planted in May 1986 in each of the eight plots for a total of 2400 trees (Figure 1). Twenty-five rows with alternating species were oriented across skidroads at a 1-m spacing. Within rows, seedlings were planted in pre-marked spots representing in the upper section the upper undisturbed soil, inner track, outer track, berm, and sidecast.

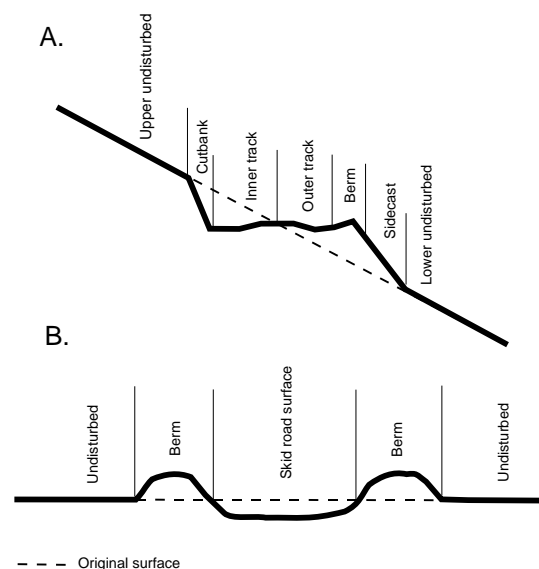


Figure 2. Skidroad and adjacent undisturbed soil categories: (A) upper section; (B) lower section



**Figure 3. Staked skidroads and adjacent undisturbed soil being prepared for planting:
(A) Plot 35 upper section; (B) Plot 32 lower section**

sidecast, and the lower undisturbed soil (one seedling per disturbance type), and in the lower section the undisturbed soil, berm and, skidroad surface (two seedlings per disturbance type) (Figures 2 and 3). Spacing of seedlings within rows varied depending on the configuration of disturbance, but was not less than 1 m.

3.3.2 Stock type, size and planting method. The Douglas-fir and lodgepole pine seedlings were 2+0 bareroot stock. Pre-planting measurements of a sample of seedlings of each species showed that Douglas-fir averaged 19 cm and lodgepole pine 25 cm in height. Douglas-fir had a 2:1 and lodgepole pine a 3:1 stem:root weight ratio. 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. Further tree measurements were made after the 8th and 10th year. Tree 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 Vegetation. Characteristics of vegetation by species and layers were measured using procedures outlined by Walmsley et al. (1980). Pre-planting and unlogged stand vegetation was assessed in 1985 using mil-acre (4.05 m²) plots established at 15-m intervals along transects. In each of the years 1985, 1986, 1987, and 1988, 117 mil-acre, tree-centered, sub-plots were surveyed within the established plots. All plants identified for each disturbance category 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 4 years of observation were tabulated by soil disturbance categories.

3.3.5 Soil water. Volumetric soil water content (top 20 cm of mineral soil) was measured in early July 1988 with an Instrument for Reflectometry Analysis of Moisture in Soils (IRAMS) (Topp et al. 1984). Moisture probes were made close to three randomly selected seedlings in each disturbance category in each of the four plots from the lower section, and in two plots from the upper section.

3.3.6 Foliage nutrients and needle weights. Samples from the second whorl current year's foliage were taken in the fall of 1990 (after five growing seasons) from six trees of each species per plot for each of the disturbance categories and undisturbed soil. A total of 432 trees were sampled. Analysis was done by the Chemical Services Laboratory of the Pacific Forestry Centre. For chemical analyses, samples were dried and 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, and total Ca, Mg, K, and Mn by 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).

3.3.7 Roots. In May, 1991 (after five growing seasons) six trees of each species per plot for each of undisturbed soil, inner track, outer track, berm, and sidecast were excavated in the upper section for a total of 240 seedlings, and six trees of each species per plot for each of undisturbed soil, berm, and skidroad surface were excavated in the lower section for a total of 144 trees. Tree selection was based on the six trees with volumes nearest the mean tree volume of all trees for each plot, species, and disturbance category combination.

Tree height and diameter at ground level were based on the 5th year growth measurements. The ground level and the upper slope side of the stem were marked. The stem was cut 5 cm above ground level and the trees excavated with mattocks and shovels to a depth required to collect the deepest roots with diameter of 2 mm or more. Lateral roots were severed 15 cm out from the base of the tree.

Root systems were transported to the laboratory, washed, then stored just above freezing temperature. Stored roots were rehydrated before measuring by soaking in water for 48 hours. The roots were suspended from a cylindrical frame 10 cm in diameter and 40 cm deep, divided into four 10-cm-deep sections or layers (Wass and Smith 1994). Each layer was divided into four equal quadrants. The cut stump was centered in the cylinder with the groundline level, with the top of the frame and the upper slope mark aligned with quadrant number one. The longitudinal axis of the main stem and root system was oriented in their original positions by using the cut plane as a horizontal reference.

The size of the root system was measured using a modification of the method devised by Lindgren and Orlander (1978); i.e., “root-area”. The diameter of each root greater than 2 mm passing through the walls of the cylinder and bottom were measured and the cross-sectional area was calculated. The root area by 10-cm layer for each tree was determined by summing these areas. The total root area for each tree is the sum of all root areas of roots passing through the walls plus the root areas of roots passing through the bottom of the last cylinder where roots occur.

The length of the taproot was measured from the top of the cylinder (frame) to where it exited the cylinder (Wass and Smith 1994). Taproots exiting the bottom of the cylinder were given a length of 40 cm. Solid-wood length and width were measured for both tree species (Wass and Smith 1994).

3.4 Data analyses

Analysis of variance (ANOVA) was performed using a general linear model procedure for unbalanced designs. The ANOVA table for analysis of tree data is presented in Appendix 1. The data for each tree species were analyzed separately. The Least-square means ($p=0.05$) was used to separate differences in disturbance category means. Chi-square tests were applied to test differences in survival of trees planted on the different disturbance categories. Percentage data were transformed to the arcsine before ANOVA. Appendices 2 and 3 present the mean square (MS), F values, and probabilities for parameters that were analyzed by disturbance category. All statistical analyses were performed with SAS computer programs (SAS Institute Inc. 1985).

4.0 Results

4.1 Undisturbed soil profile characteristics

The soil was identified as an Eluviated Dystric Brunisol (Agriculture Canada Expert Committee on Soil Survey 1987), which developed from a gravelly (cobbly) glacio-fluvial deposit with a finer-textured, 22-to 32-cm-thick Bm overlay. The thin (3 cm) humus was a humi-fibrimor (Klinka et al. 1981) with concentrations of 39% organic carbon and 1.03% total nitrogen, and a C:N ratio of 39. Mineral soil textures varied from sand through loamy sand to sandy loam with sand constituting 72-90%, silt 3-20% and clay 7-8% of the whole. Coarse fragments were visually estimated to make up from 10% of soil volume at the surface to 65% at depth. The concentration of organic carbon decreased sharply with depth in the upper 40 cm and then maintained a consistently low level with increasing depth (Figure 4A). The concentration of total nitrogen showed a similar pattern to that of organic carbon (Figure 4B). The C:N ratio was too erratic to suggest any pattern associated with soil depth (Figure 4C). The mineral soil pH was highest at the surface and maintained a lower but fairly constant level with increasing depth (Figure 4D).

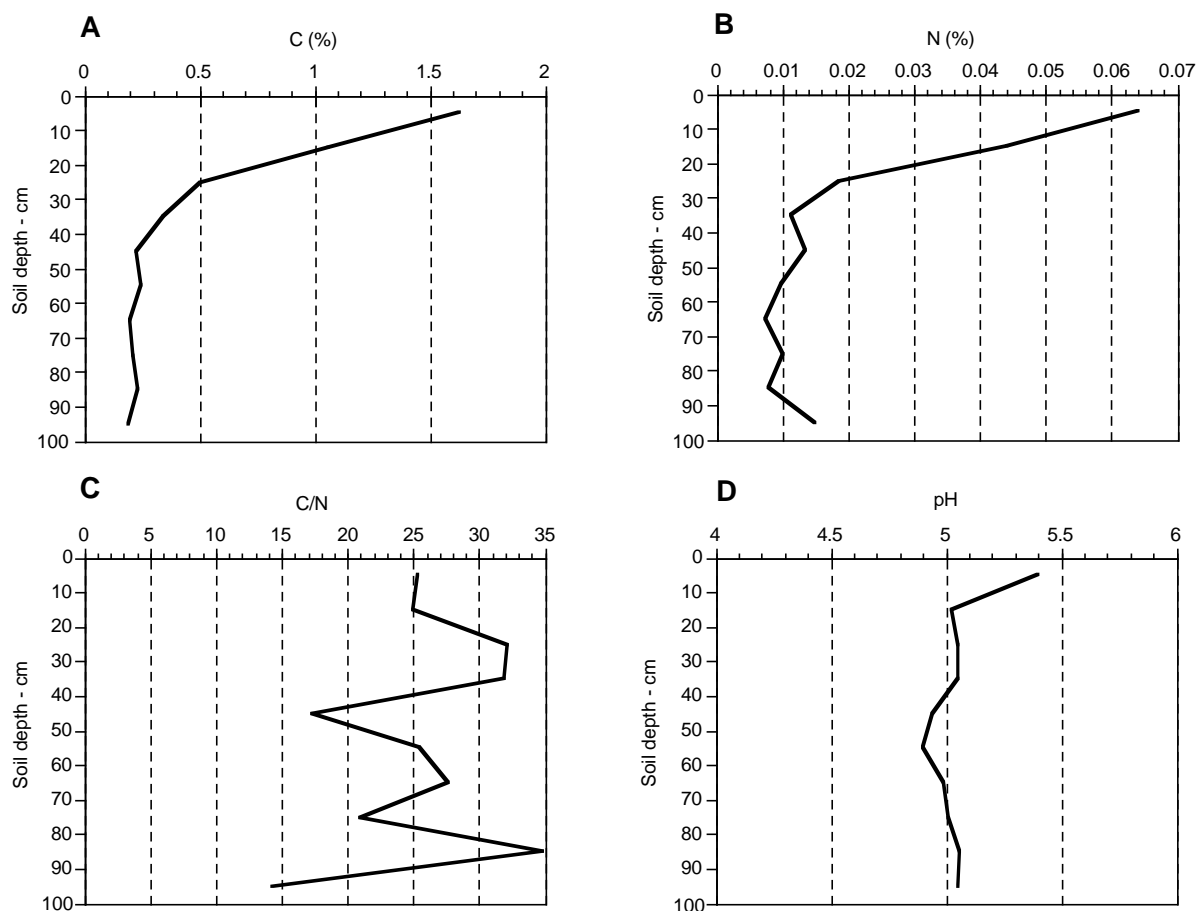


Figure 4. Trends in some chemical characteristics with increasing depth of undisturbed mineral soil: (A) Organic carbon; (B) Total nitrogen; (C) Carbon/nitrogen; (D) pH (CaCl₂)

Using our description of the soils and keys developed for rating the sensitivity of forest sites to soil disturbance (British Columbia Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995), the lower section was rated low to moderately sensitive to soil compaction and puddling, moderate for displacement and mass wasting, and high for forest floor displacement and surface soil erosion. The upper section was rated low to moderately sensitive to soil compaction and puddling, and high for displacement, forest floor displacement, surface soil erosion, and mass wasting (due to underlying non-cohesive material and potential for dry raveling).

4.2 Ground surface conditions

One hundred percent of the uncut stand was classified as undisturbed (Table 1). Average depth of humus was 3 cm, 80% of which was classified as humified with no rotten wood, 6% as rotten wood, 13% as mixtures of rotten wood and humified material, and 1% as not present. Sound woody debris covered 16% and natural, rotting logs covered 14% of the ground surface.

Forty-five percent of the cutblock was disturbed, most of this (39%) caused by skidroad construction (Table 1). Most of the remaining disturbance resulted from non-constructed skidtrails. Of the disturbance, 67% was very deep (> 25 cm) and 33% was deep (5-25 cm).

4.3 Soil bulk density

Upper Section: Total bulk density of the soil at 0-10 cm was greatest in the skidroad surface, significantly greater than the undisturbed soil (Table 2). The total bulk density at the 10-to 20-cm depth in the skidroad surface was significantly greater than for the berm and undisturbed soil. The fine bulk density for skidroad surface at the 10-to 20-cm depth was significantly greater than the berm and undisturbed soil.

Lower Section: Total bulk density of the soil at 0-10 cm and 10-20 cm was greatest in the skidroad surface, significantly greater than in the berm and undisturbed soil (Table 2). At the 0-to 10-cm soil depth, bulk density of the fine soil was significantly greater on the skidroad surface than in the berm and undisturbed soil, but significantly greater at the 10-to 20-cm depth only for the berm.

4.4 Penetrability

Upper Section: Soils in the skidroad surface showed significantly greater resistance to penetration than soils in berms for depths 2.5 to 20 cm and undisturbed soils for depths 7.5 cm to 20 cm (Figure 5). Soil from the berm was more easily penetrated than undisturbed soil, significantly so at the soil surface (0 cm) and at depths of 2.5, 5, and 10 cm.

Lower Section: The skidroad surface showed significantly greater resistance to penetration than the undisturbed soil at 5-to 20-cm depth and in berms for all depths tested to 20 cm (Figure 6). Additionally, undisturbed soil was more easily penetrated than soil from the berm, but significantly so only at the soil surface.

4.5 Coarse fragment content

Upper Section: The coarse fragment content of the upper 10 cm of undisturbed soil was significantly less than for the top 10 cm of soil from the skidroad surface and berm (Table 3).

Lower Section: The coarse fragment content for the 10-to 20-cm depth was significantly greater for soil in the skidroad surface than for the berm and undisturbed soil. (Table 3).

4.6 Soil chemical characteristics

Upper Section: At a soil depth of 0-10 cm, the concentration of organic carbon and total nitrogen were significantly less for the skidroad surface than for the undisturbed soil (Table 4). At a soil depth of 10-20 cm, soil from the berm had a significantly greater concentration of organic carbon than the skidroad surface.

Lower Section: At a soil depth of 10-20 cm, the concentration of organic carbon and total nitrogen were significantly greater for the berm than for undisturbed soil and the skidroad surface (Table 4).

4.7 Volumetric soil water content

Upper Section: The lower undisturbed soil had a significantly greater volumetric soil water content at 0- to 20-cm depth than the soil from the inner track, outer track, berm and sidecast (Table 5). Soil water content was significantly greater in the upper undisturbed soil than in the outer track, berm and sidecast.

Lower Section: The berm had significantly less volumetric soil water content at 0- to 20-cm depth than the undisturbed soil and skidroad surface (Table 6).

4.8 Seedling survival

Upper Section: After 5 years, Douglas-fir and lodgepole pine seedlings exhibited significantly poorer survival in the berm than in the other disturbance categories (Table 7). Highest survival for Douglas-fir occurred on the inner track, and was significantly greater there than on the outer track, sidecast or berm. Lodgepole pine had almost twice the percentage of surviving trees as Douglas-fir when both grew in the berm.

Lower Section: Survival of lodgepole pine was significantly less in the berm than in undisturbed soil or the skidroad surface (Table 7).

Average survival for Douglas-fir in the lower section was 14% higher than in the upper section. In comparison, the difference in percentage survival between the sections was only 1% for lodgepole pine.

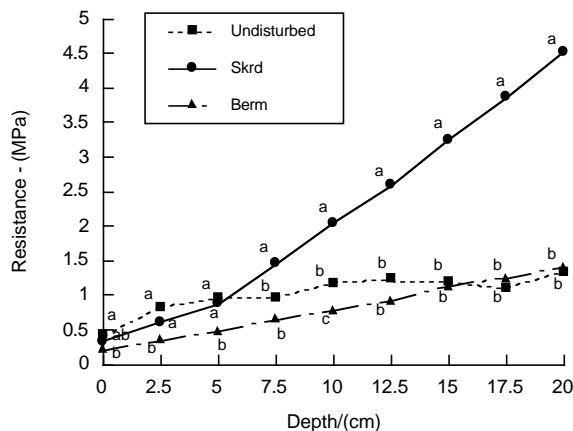


Figure 5. Resistance to penetration (MPa) of skidroad surface (Skrd), berm, and undisturbed mineral soil to a depth of 20 cm for the upper section. Means at the same depth with the same letter are not significantly different at the 0.05 level.

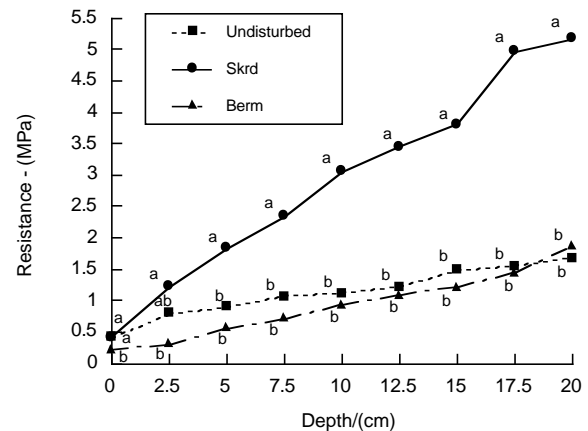


Figure 6. Resistance to penetration (MPa) of skidroad surface (Skrd), berm, and undisturbed mineral soil to a depth of 20 cm for the lower section. Means at the same depth with the same letter are not significantly different at the 0.05 level.

4.9 Seedling growth

Upper Section: Measurements made immediately after planting showed that there were no significant differences in the height of lodgepole pine and Douglas-fir among disturbance categories. Mean height and diameter of lodgepole pine seedlings after five and ten growing seasons were not significantly different among disturbance categories (Table 8). Mean height of Douglas-fir seedlings after five growing seasons on the lower undisturbed soil was significantly greater than mean height of seedlings on the inner track (Table 9). After ten growing seasons, the mean height of Douglas-fir planted in the berm was significantly greater than for seedlings planted in the inner track and upper undisturbed soil, while trees on the upper undisturbed soil were significantly shorter than trees on all the other categories except the inner track (Table 9). Mean diameter of Douglas-fir seedlings growing in the berm was significantly greater than for seedlings planted in the other disturbance categories (Table 9).

Heights of Douglas-fir and lodgepole pine seedlings growing in disturbed soil were compared with their growth in undisturbed soil (upper and lower undisturbed categories combined) for the period from 1986 to 1995 (Figure 7). By the 2nd year, lodgepole pine seedlings on all disturbed soils were showing reduced height

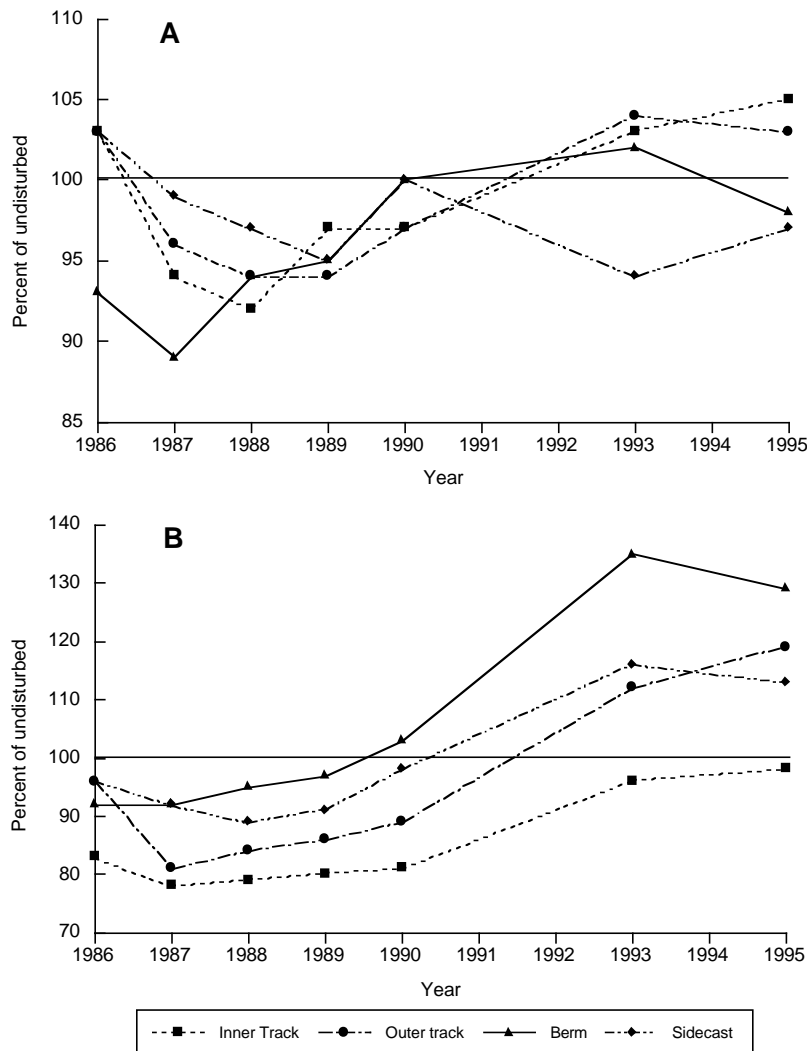


Figure 7. Height of seedlings growing on disturbed soil as a percentage of height of seedlings grown in an undisturbed soil for the upper section: (A) lodgepole pine; (B) Douglas-fir

growth relative to those growing in undisturbed soils (Figure 7A). However, by the 10th year, lodgepole pine seedlings on inner and outer tracks had height growth greater than those growing in undisturbed soil.

By the 1st year, Douglas-fir seedlings on all disturbed soils were showing reduced height relative to those growing in undisturbed soil (Figure 7B). By the 8th year, height growth for Douglas-fir seedlings from the berm, sidecast, and outer track ranged from 112 to 135% of that for Douglas-fir growing in undisturbed soil. The mean height of seedlings growing in the inner track remained slightly below that for the undisturbed soil by the 10th year.

Lower Section: Measurements made immediately after planting showed that there were no significant differences in the height of lodgepole pine and Douglas-fir among disturbance categories. Mean height and diameter of lodgepole pine and Douglas-fir seedlings after five and ten growing seasons were not significantly different among disturbance categories (Tables 10 and 11).

Heights of Douglas-fir and lodgepole pine seedlings growing in disturbed soil were compared with their growth in the undisturbed soil for the period from 1986 to 1995. By the 8th year, lodgepole pine seedlings growing in the berm and skidroad surface had equalled or exceeded the height of seedlings growing in the undisturbed soil (Figure 8A)

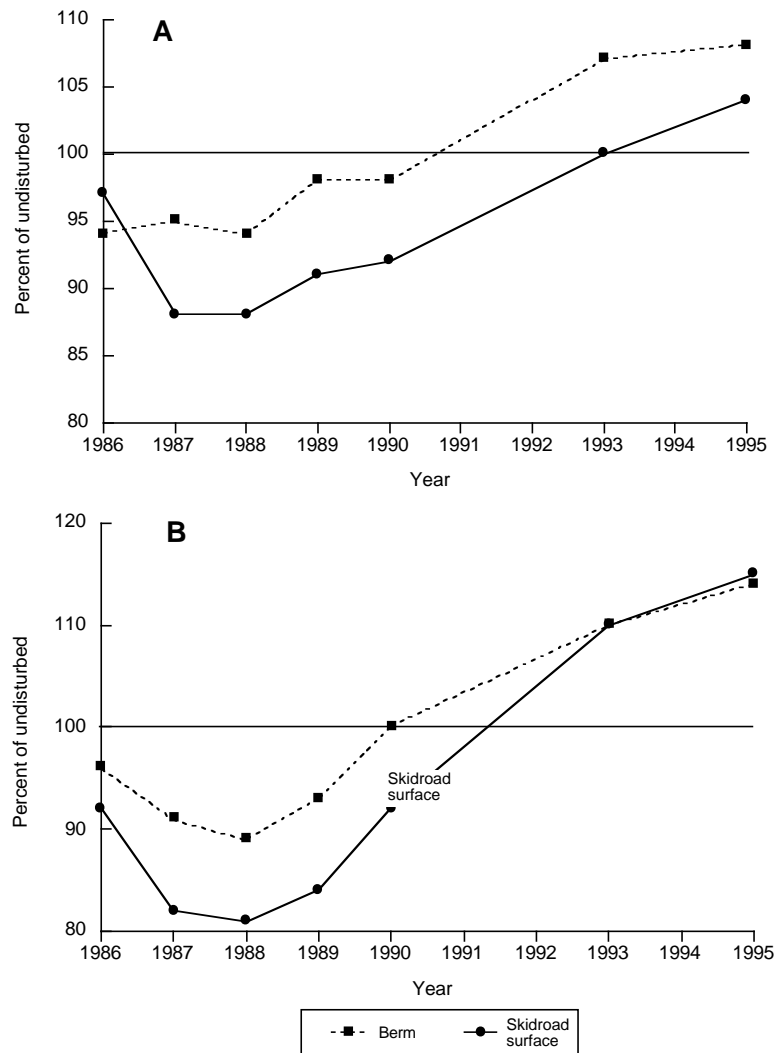


Figure 8. Height of seedlings growing on disturbed soil as a percentage of height of seedlings grown in an undisturbed soil for the lower section: (A) lodgepole pine, (B) Douglas-fir

By the 1st year, Douglas-fir seedlings in both berm and skidroad surface were showing reduced height growth relative to those growing in undisturbed soil (Figure 8B). By the 8th year, Douglas-fir seedlings on disturbed soils were showing heights exceeding those of seedlings growing in undisturbed soil.

4.10 Foliage nutrients

Upper Section: There were no significant differences by disturbance categories for the elements K, Ca, Mg, S, Mn, and total Fe for Douglas-fir foliage. The concentration of N was significantly greater for seedlings growing in the sidecast than in the upper undisturbed soil (Table 12). The concentration of P in Douglas-fir foliage was significantly greater for seedlings growing in the inner track than in other disturbance categories, except the outer track and sidecast.

Based on Ballard and Carter's (1986) nutrient deficiency program, Douglas-fir foliage was, on average, severely deficient in N for all disturbance categories. Magnesium may have been deficient for all disturbance categories except inner and outer track. Calcium may have been deficient for seedlings growing in the inner track.

For lodgepole pine, there were no significant differences by disturbance categories for the elements N, P, K, Ca, S, and Total Fe (Table 12). The concentrations of Mg and Mn were significantly greater for foliage from seedlings growing in the inner track than in upper undisturbed soil (Table 12).

For lodgepole pine, foliage nitrogen was severely deficient for all disturbance categories except sidecast, which was slightly to moderately deficient. Phosphorus was slightly to moderately deficient for trees in all disturbance categories except in the lower undisturbed soil, where they were not deficient. Magnesium was slightly to moderately deficient for trees in all disturbance categories except the inner track.

Lower Section: There were no significant differences by disturbance categories for all the elements N, K, Ca, S, Mg, and total Fe for Douglas-fir foliage (Table 13). The concentration of P was significantly greater for seedlings growing in the skidroad surface than in the undisturbed soil (Table 13). The concentration of Mn was significantly less for seedlings from the undisturbed soil than for the seedlings from the skidroad surface and berm.

Based on Ballard and Carter's (1986) nutrient deficiency program, Douglas-fir foliage was, on average, severely deficient in N for all disturbance categories.

For lodgepole pine, there were no significant differences by disturbance categories for any of the elements (Table 13).

For lodgepole pine, nitrogen was severely deficient, P was slightly deficient, and Mg was slightly to moderately deficient for all disturbance categories.

4.11 Vegetation

For both sections, the average total vegetative cover in the adjacent unlogged stand (92%) was used as the unharvested starting point (Figure 9).

Upper Section : Vegetative cover reached its lowest point 3 years after harvesting for all soil categories, with the inner track the lowest at 16% (Figure 9A). Five years after harvesting, vegetative cover for the inner track had recovered to 30%, with the other disturbance categories ranging from 47 to 62% (Figure 9A).

In comparisons among disturbance categories, vegetation composition and cover were found to be most dissimilar between unlogged and the other disturbance categories, and least dissimilar between outer track, and berm (Table 14). Differences in vegetation were great between the logged undisturbed (upper and lower) and both the inner and outer track with dissimilarly indices ranging from 93-95% (Table 14).

Amelanchier alnifolia Nutt., *Linnaea borealis* L., and *Paxistima myrsinites* (Pursh) Raf. were found frequently only on undisturbed soil (Table 15). *Trifolium pratense* L., *Trifolium hybridum* L., *Festuca occidentalis* Hook. and *Festuca rubra* L. were found frequently only on disturbed soil.

Lower Section: Vegetative cover reached its lowest point 3 years after harvesting for all three disturbance categories, with the skidroad surface least at 19% (25% for berm and 36% for undisturbed soil) (Figure 9B). By 5 years after harvesting, vegetative cover had recovered to 56% for undisturbed soil, 55% for berm, and 43% for the skidroad surface.

In comparisons among disturbance categories, vegetation composition and cover were found to be most dissimilar between the unlogged stand and the skidroad surface, and least dissimilar between undisturbed soil and the berm (Table 16). *Amelanchier alnifolia*, *Linnaea borealis*, *Paxistima myrsinites*, *Shepherdia canadensis* (L.) Nutt., *Berberis aquifolium* Pursh, and *Oryzopsis asperifolia* Michx. were found frequently only on undisturbed soil (Table 17). *Festuca rubra*, *F. occidentalis*, *Trifolium pratense* and *T. hybridum* were found frequently only on disturbed soil. *Epilobium angustifolium* L., and *Calamagrostis rubescens* Buckl. were found frequently only on the skidroad berm. *Spiraea betulifolia* Pall. and *Ceanothus sanguineus* Pursh were found frequently on all disturbance categories.

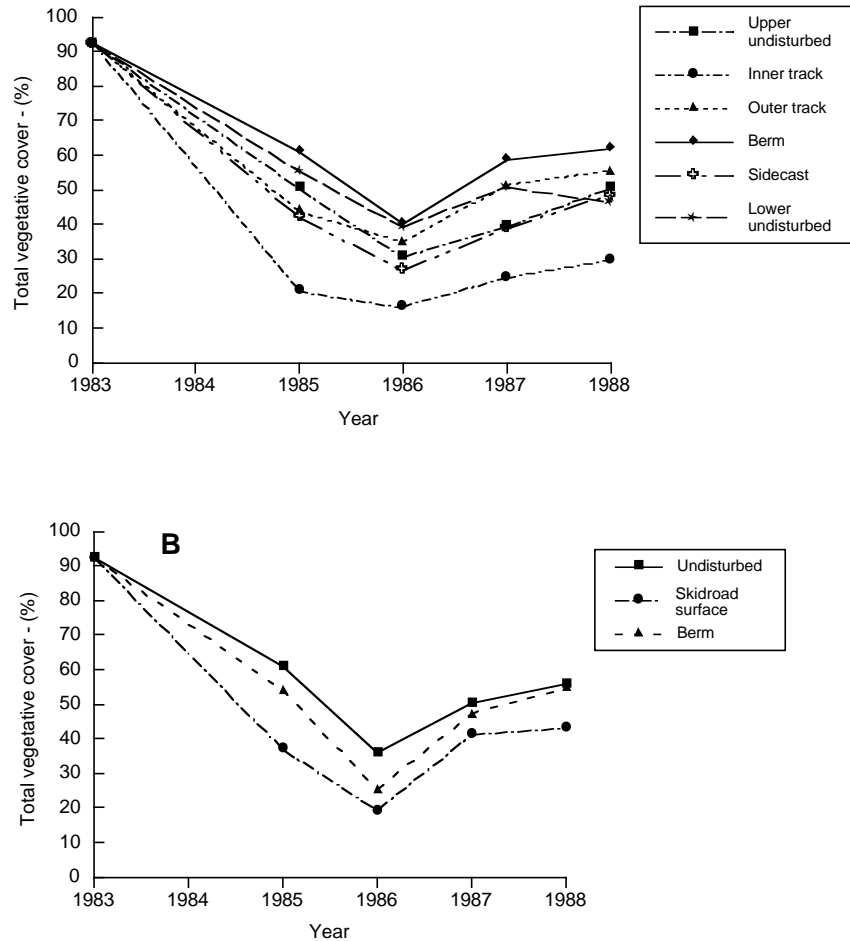


Figure 9. Trends in total vegetative cover following clearcut logging for undisturbed soil and skidroad disturbance categories: (A) upper section; (B) lower section. Initial cover comes from an adjacent unlogged stand.

4.12 Roots

Upper Section: Lodgepole pine solid-wood width, and ground-level diameter were not significantly different for disturbance categories (Table 18). The solid-wood length was significantly less for trees growing in the upper undisturbed soil than for trees on the berm. Root depth for trees on the sidecast was significantly deeper than for trees on the inner and outer tracks, and deeper in the berm than in the outer track. For root area at the 0-10 cm and 20-30 cm layers and total root area, there were no significant differences between disturbance categories (Table 19). For the 10-20 cm layer, trees on the berm had a significantly greater root area than trees on the upper undisturbed, inner track and, outer track. For the 30-40 cm layer, root area was significantly less for upper undisturbed, inner track, and outer track than for trees in the berm and sidecast.

For Douglas-fir growing on the lower undisturbed soil, ground-level diameter was significantly greater than for trees growing on the inner track (Table 18). Solid-wood width was significantly greater for trees on the lower undisturbed soil than for trees on the inner and outer tracks. Trees from the berm had significantly deeper roots than trees from the inner and outer tracks. For the 0-10 cm and 10-20 cm layers, root area was significantly greater for trees on the berm than for trees growing on the inner and outer tracks (Table 19). At the 20-30 cm layer, the root area was significantly greater for trees on the berm than for trees on all of the other disturbance categories. For root area at the 30-40 cm layer and for total root area, there were no significant differences between disturbance categories.

Lower Section: Lodgepole pine ground-level diameter and solid-wood length and width were not significantly different by disturbance category (Table 20). Tree root depth was significantly deeper for trees growing in the berm than for those on the undisturbed soil and skidroad surface. There were no significant differences among the disturbance categories for root area by layers or total (Table 21).

For Douglas-fir, there were no significant differences in ground-level diameter, solid-wood length or width, or root depth by disturbance category (Table 20). At the 20-30 cm layer, the root area for trees growing in the berm was significantly greater than for trees on the undisturbed soil or skidroad surface (Table 21). For the 0-10 cm, 10-20 cm and 30-40 cm layers, and total there were no significant differences in root area by disturbance category.

5.0 Discussion and Conclusions

The 39% coverage of skidroads, their average width of 8.4 m, and the 67% of skidroad disturbance categorized as very deep (>25 cm) compare closely with 32%, 7.9 m, and 66%, respectively, in a regional survey in southeastern British Columbia (Smith and Wass 1976). However, being oriented largely downhill as opposed to the more common contour pattern used on steep slopes, the depth of disturbance (i.e., cut and fill), and thus the overall width of the skidroads should, in theory, have been substantially less (Homoky, 1994). Downward orientation did result in skidroad grades that had to conform closely to the natural slope. This resulted in grades in the upper section that were more than 100% and in the lower section more than 35% greater than those found for comparable slopes in the regional study (Smith and Wass 1976). Considering these soil disturbance measures alone, the concern of forest managers about soil erosion and productivity loss was well justified.

Details of the changes in soil characteristics from the undisturbed state wrought by the skidroad construction also point to overall site deterioration. These include significantly greater soil density and reduced penetrability in the surface 20 cm at least of skidroad running surfaces compared with undisturbed soil in both the upper and lower sections. These densities exceed those found to restrict root growth of Douglas-fir and lodgepole pine (Heilman 1981; Minore et al. 1969). The content of coarse fragments was also greater on the skidroad surfaces, reaching as much as 71%. However, largely as a result of the high coarse fragment content, active compaction by skidders was not evident from comparisons of densities in the skidroads with equivalent depths in the undisturbed soil. Generally, the upper section had higher bulk densities and greater coarse fragment content than the lower section.

In the upper section, the concentration of soil nitrogen and organic carbon was significantly greater in the top 10 cm of the undisturbed soil than in the skidroad running surface, but not in the lower section. In the lower section at depth 10-20 cm, the berm had significantly greater concentrations of these elements than in undisturbed soil.

Soil moisture retention was adversely affected by the skidroad construction, with mid-summer volumetric moisture significantly less in the outer track, berm and sidecast of the upper section, and in the berm of the lower section than in undisturbed soil. Some inferior soil characteristics were reflected in the significantly poorer survival of both lodgepole pine and Douglas-fir planted on berms in the upper section and of lodgepole pine in the lower section. This is attributed to low water retention in these loose, moisture shedding substrates and to competition with the seeded grasses and legumes. Poor survival on deposits relative to more compacted surfaces such as tracks have been reported for lodgepole pine and Douglas-fir on stump removal deposits (Smith and Wass 1994b), and for Douglas-fir on skidroad sidecast (Smith and Wass 1994a). In contrast, on compacted tracks subject to seasonal water saturation, survival rates for Douglas-fir and lodgepole pine were significantly less than in more convex and less dense rakes and scalps (Smith and Wass 1991).

Despite the several indications of degraded soils on skidroads, the size of lodgepole pine was not significantly different on undisturbed and disturbed soil categories for either the upper or lower sections. For Douglas-fir growing on the berm, mean tree sizes after 10 years were significantly greater than those for undisturbed soil in three of six comparisons.

In the upper section, height of Douglas-fir was significantly greater on undisturbed soil below the skidroads than above. This can be explained at least partially by lower soil water content in the upper position. The low vigor of trees here corresponded to nutrient concentrations of Douglas-fir foliage, which ranked lowest for trees growing in both undisturbed categories and ranked especially low for lodgepole pine growing in the upper undisturbed position. The concentration of N in foliage of Douglas-fir from the upper undisturbed soil was significantly less than in foliage from trees on the sidecast, and P was significantly less in the upper undisturbed soil than in the inner tracks.

The artificial seeding of grasses and legumes on the skidroads had a strong effect on vegetation cover and composition. Only seeded species were recorded in more than 40% of subplots on skidroad surfaces over the 4 years of measurements. On the berm and sidecast in the upper section and the berm in the lower section, plant species other than those seeded were recorded frequently, but overall cover was still increased appreciably by the seeding, especially on the berm of the upper section. The seeding obviously contributed to the high percentage dissimilarity values calculated in comparisons of plant cover and composition between disturbed and undisturbed surfaces. The very high cover of seeded species on berms in the upper section also likely contributed to the low seedling survival rates here. Whether the establishment of seeded legumes affected tree nutrition and growth can not be determined. In work with Alsike clover, Trowbridge and Holl (1992) found that lodgepole pine height growth 4 years after outplanting was slightly less on clover-seeded plots than these of the control plots, and tree diameter was not significantly different. They also reported that lodgepole pine associated with Alsike clover had significantly greater needle mass and foliar N levels. In our study, N concentrations were generally higher in the foliage of trees growing in disturbed than in undisturbed soil.

In the most recent site sensitivity keys (British Columbia Ministry of Forests and B.C. Ministry of Environment, Lands and Parks 1995), the study site would be assessed as low to moderate hazard for soil compaction and puddling. This corresponds to a lack of adverse growth effects found in our study. However, a high forest floor displacement hazard rating coupled with the severity of soil displacement should have resulted in severe adverse growth effects. That it did not may be due to elimination of potentially competing residual vegetation on the disturbed soil on this sub-mesic site and, as noted earlier, some growth benefit resulting from the presence of seeded nitrogen-fixing plants almost solely on disturbed soil. Using a simpler rating system geared solely to effects on tree growth potential (Smith and Wass 1980), the study site would be assessed as posing no problems in terms of growth rates of trees established on skidroads and even some growth enhancement. Not measured, however, was the observed slumping and ravelling of cutbanks in the steep upper section, with the probability of loss in overall site productivity.

Further measurements at 15 and 20 years would reveal whether the relatively small effects of skidroad construction and use on tree growth over the first 10 years will continue. It is possible that increased vegetative and tree-to-tree competition and reduced cover of seeded nitrogen-fixing plants will result in relatively slower growth rates on disturbed soil. There is also an opportunity to re-measure soil chemical and physical properties, foliage nutrient contents, and plant species and cover to compare with initial values.

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Table 1. Categories and depths of soil disturbance in the skidded site versus an unlogged stand bordering the cutblock

Treatment	Disturbance category	Depth of soil disturbance				Total
		None	Shallow <5 cm	Deep 5-25 cm	Very deep > 25 cm	
----- % -----						
Uncut	Undist	86	0	0	0	86
	Undist (NL)	14	0	0	0	14
	Total	100	0	0	0	100
Logged	Undist	55	0	0	0	55
	Skidroad	0	0	10	29	39
	Non-road dist.	0	0	2	0	2
	Skidtrails	0	0	3	1	4
	Total	55	0	15	30	100

Undist=undisturbed; dist=disturbance; NL=Natural log

Table 2. Mean bulk density (Mg/m³) of total and fine soil fractions for two disturbance categories plus the undisturbed mineral soil at two depths

Section	Disturbance	Number of samples	Depth			
			Total bulk density		Fine bulk density	
			0-10 cm	10-20 cm	0-10 cm	10-20 cm
Upper	Undisturbed	8	1.41 b*	1.52 b	0.95 a	0.94 b
	Berm	8	1.68 a	1.64 b	0.96 a	0.91 b
	Skidroad surface	8	1.74 a	1.93 a	1.03 a	1.17 a
Lower	Undisturbed	8	1.30 b	1.35 b	0.99 b	1.04 ab
	Berm	8	1.28 b	1.23 b	0.89 b	0.86 b
	Skidroad surface	8	1.65 a	1.79 a	1.20 a	1.19 a

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

Table 3. Coarse fragment content of bulk density samples

Section	Disturbance category	Number of samples	Percent coarse fragment content	
			0-10 cm	10-20 cm
Upper	Undisturbed	8	50 b*	58 a
	Skidroad surface	8	67 a	71 a
	Berm	8	67 a	67 a
Lower	Undisturbed	8	37 a	35 b
	Skidroad surface	8	50 a	60 a
	Berm	8	46 a	46 b

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

Table 4. Chemical characteristics of bulk density samples

Section	Depth (cm)	Disturbance category	Organic carbon (%)	Total nitrogen (%)	C:N ratio	pH
Upper	0-10	Undisturbed	1.90 a*	0.08 a	25.5 a	5.50 a
		Skidroad surface	0.87 b	0.04 b	22.7 a	5.50 a
		Berm	1.56 ab	0.06 ab	24.8 a	5.54 a
	10-20	Undisturbed	1.11 ab	0.04 a	26.2 a	4.71 a
		Skidroad surface	0.65 b	0.04 a	21.8 a	5.62 a
		Berm	1.42 a	0.06 a	27.2 a	5.53 a
Lower	0-10	Undisturbed	1.32 a	0.05 a	25.1 a	5.30 a
		Skidroad surface	1.14 a	0.05 a	20.3 a	5.33 a
		Berm	1.97 a	0.07 a	28.0 a	5.36 a
	10-20	Undisturbed	1.01 b	0.05 b	23.9 a	5.33 a
		Skidroad surface	1.13 b	0.04 b	21.9 a	5.18 a
		Berm	2.11 a	0.07 a	29.1 a	5.37 a

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

Table 5. Mean mid-summer volumetric soil water content (upper 20 cm) for six disturbance categories, upper section

Species	Disturbance categories					
	Upper undisturbed	Inner track	Outer track	Berm	Sidecast	Lower Undisturbed
	----- % -----					
Lodgepole pine	5.3 b*	4.9 b	3.3 c	2.5 c	2.5 c	6.7 a
Douglas-fir	6.1 a	4.4 a	3.6 a	3.0 a	3.1 a	6.0 a
Average	5.7 ab	4.6 b	3.4 c	2.8 c	2.9 c	6.4 a

* Means within rows having the same letter are not significantly different at the 0.05 level.

Table 6. Mean mid-summer volumetric soil water content (upper 20 cm) for three disturbance categories, lower section

Species	Disturbance categories		
	Undisturbed	Skidroad surface	Berm
	----- % -----		
Lodgepole pine	8.6 a*	9.1 a	6.2 a
Douglas-fir	9.6 a	8.0 ab	6.0 b
Average	9.1 a	8.6 a	6.1 b

* Means within rows having the same letter are not significantly different at the 0.05 level.

Table 7. Survival rates of Douglas-fir and lodgepole pine seedlings planted on skidroad soil disturbance categories and undisturbed ground after five growing seasons

Section	Disturbance	Douglas-fir		Lodgepole pine	
		No. of trees	Survival-(%)	No. of trees	Survival-(%)
Upper	Upper undisturbed	97	76 ab*	98	89 a
	Inner track	95	86 a	96	95 a
	Outer track	95	73 b	94	88 a
	Berm	95	43 c	94	75 b
	Sidecast	94	70 b	95	88 a
	Lower undisturbed	93	81 ab	91	91 a
Lower	Undisturbed	190	85 a	185	89 a
	Berm	190	82 a	190	80 b
	Skidroad surface	190	89 a	190	93 a

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

Table 8. Mean heights and ground-level diameters of lodgepole pine seedlings for disturbance categories and undisturbed mineral soil (upper section)

Years after planting	Disturbance category	Number of trees	Height (cm)	Diameter (mm)
5	Upper undisturbed	87	109 a*	23.2 a
	Inner track	91	103 a	22.3 a
	Outer track	83	103 a	22.1 a
	Berm	70	102 a	22.9 a
	Sidecast	84	106 a	21.3 a
	Lower undisturbed	83	114 a	22.2 a
10	Upper undisturbed	42	335 a	67 a
	Inner track	28	365 a	71 a
	Outer track	29	359 a	74 a
	Berm	32	343 a	68 a
	Sidecast	26	338 a	69 a
	Lower undisturbed	38	363 a	67 a

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

Table 9. Mean heights and ground-level diameters of Douglas-fir seedlings for disturbance categories and undisturbed mineral soil (upper section)

Years after planting	Disturbance category	Number of trees	Height (cm)	Diameter (mm)
5	Upper undisturbed	74	58 ab*	15.0 a
	Inner track	82	52 b	14.1 a
	Outer track	69	58 ab	15.0 a
	Berm	41	68 ab	17.6 a
	Sidecast	66	62 ab	15.2 a
	Lower undisturbed	75	70 a	16.7 a
10	Upper undisturbed	38	150 c	35 b
	Inner track	25	166 bc	37 b
	Outer track	30	201 ab	45 b
	Berm	14	227 a	54 a
	Sidecast	29	198 ab	40 b
	Lower undisturbed	37	194 ab	40 b

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

Table 10. Mean heights and ground-level diameters of lodgepole pine seedlings for disturbance categories and undisturbed mineral soil (lower section)

Years after planting	Disturbance category	Number of trees	Height (cm)	Diameter (mm)
5	Undisturbed	165	142 a*	29.8 a
	Berm	152	139 a	31.3 a
	Skidroad surface	177	131 a	29.3 a
10	Undisturbed	79	381 a	81 a
	Berm	57	410 a	89 a
	Skidroad surface	57	398 a	80 a

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

Table 11. Mean heights and ground-level diameters of Douglas-fir seedlings for disturbance categories and undisturbed mineral soil (lower section)

Years after planting	Disturbance category	Number of trees	Height (cm)	Diameter (mm)
5	Undisturbed	161	85 a*	19.9 a
	Berm	156	86 a	20.3 a
	Skidroad surface	169	79 a	19.5 a
10	Undisturbed	79	239 a	48 a
	Berm	63	273 a	59 a
	Skidroad surface	53	275 a	59 a

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

Table 12. Mean concentration of nutrients in foliage of Douglas-fir and lodgepole pine for the upper section for four skidroad categories and the undisturbed soil (Basis: 24 trees for each disturbance category)

Species	Nutrient	Disturbance category					
		Upper undisturbed	Inner track	Outer track	Berm	Sidecast	Lower undisturbed
Douglas-fir		----- % -----					
	N	1.09 b*	1.16 ab	1.15 ab	1.27 ab	1.29 a	1.16 ab
	P	0.168 bc	0.224 a	0.209 ab	0.167 c	0.186 abc	0.169 bc
	K	0.80 a	0.88 a	0.81 a	0.89 a	0.85 a	0.86 a
	Ca	0.29 a	0.23 a	0.31 a	0.31 a	0.30 a	0.29 a
	Mg	0.110 a	0.130 a	0.128 a	0.111 a	0.117 a	0.107 a
	S	0.176 a	0.159 a	0.197 a	0.181 a	0.172 a	0.185 a
		----- ppm -----					
	Mn	153.3 a	176.7 a	184.3 a	168.1 a	153.5 a	130.2 a
	Total Fe	74.7 a	62.3 a	61.2 a	60.9 a	68.3 a	57.3 a
Lodgepole pine		----- % -----					
	N	1.09 a	1.15 a	1.19 a	1.15 a	1.24 a	1.12 a
	P	0.112 a	0.125 a	0.127 a	0.120 a	0.121 a	0.164 a
	K	0.51 a	0.51 a	0.53 a	0.57 a	0.56 a	0.59 a
	Ca	0.23 a	0.24 a	0.23 a	0.21 a	0.22 a	0.26 a
	Mg	0.078 b	0.096 a	0.087 ab	0.087 ab	0.083 ab	0.088 ab
	S	0.148 a	0.169 a	0.176 a	0.156 a	0.174 a	0.162 a
		----- ppm -----					
	Mn	83.8 b	130.7 a	117.4 ab	116.5 ab	100.0 ab	96.2 ab
	Total Fe	72.2 a	71.0 a	61.7 a	59.5 a	59.2 a	56.2 a

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

Table 13. Mean concentration of nutrients in foliage of Douglas-fir and lodgepole pine for the lower section for two skidroad categories and the undisturbed soil (Basis: 24 trees for each disturbance category)

Species	Nutrient	Disturbance category		
		Undisturbed	Berm	Skidroad surface
Douglas-fir	----- % -----			
	N	1.13 a*	1.19a	1.17 a
	P	0.178 b	0.191 ab	0.235 a
	K	0.83 a	0.83 a	0.86 a
	Ca	0.31 a	0.33 a	0.34 a
	Mg	0.106 a	0.119 a	0.136 a
	S	0.178 a	0.178 a	0.169 a
	----- ppm -----			
	Mn	158.4 b	214.2 a	242.6 a
	Total Fe	75.3 a	80.3 a	65.5 a
Lodgepole pine	----- % -----			
	N	1.11 a	1.11 a	1.25 a
	P	0.121 a	0.123 a	0.132 a
	K	0.55 a	0.56 a	0.58 a
	Ca	0.25 a	0.23 a	0.21 a
	Mg	0.084 a	0.087 a	0.088 a
	S	0.162 a	0.159 a	0.183 a
	----- ppm -----			
	Mn	107.1 a	105.0 a	122.2 a
	Total Fe	74.0 a	70.8 a	90.2 a

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

Table 14. Average dissimilarity indices (%) for the upper section based on average vegetation composition and cover over 4 years (1985-1988) for disturbance category comparisons (Basis: 20 subplots for berm and sidecast, 11 for inner track, 9 for outer track, and 5 for upper and lower undisturbed categories)

	Unlogged	Upper undisturbed	Lower undisturbed	Inner track	Outer track	Berm	Sidecast
Unlogged	0	98	97	100	100	100	99
Upper undisturbed		0	44	94	93	72	53
Lower undisturbed			0	95	95	73	56
Inner track				0	38	55	67
Outer track					0	27	72
Berm						0	46
Sidecast							0

Table 15. Average frequency (%) and cover (%) of plants (1985-1988) present in more than 40% of sampled plots, upper section

Species	Undisturbed		Berm		Sidecast		Skidroad surface	
	Freq.	Cover	Freq.	Cover	Freq.	Cover	Freq.	Cover
<i>Amelanchier alnifolia</i>	75	4	-	-	-	-	-	-
<i>Linnaea borealis</i>	63	3	-	-	-	-	-	-
<i>Paxistima myrsinites</i>	73	1	-	-	-	-	-	-
<i>Rosa nutkana</i>	68	5	63	5	76	7	-	-
<i>Spiraea betulifolia</i>	90	7	80	4	99	5	-	-
<i>Epilobium minutum</i>	55	1	56	1	73	2	-	-
<i>Berberis aquifolium</i>	80	2	-	-	-	-	-	-
<i>Carex rossii</i>	58	2	-	-	65	2	-	-
<i>Calamagrostis rubescens</i>	98	11	-	-	60	2	-	-
<i>Festuca rubra</i> *	-	-	53	19	41	4	49	13
<i>Trifolium hybridum</i> *	-	-	76	5	-	-	93	4
<i>Festuca occidentalis</i> *	-	-	48	13	-	-	50	9
<i>Trifolium pratense</i> *	-	-	45	2	-	-	89	5

* Operationally seeded

Table 16. Average dissimilarity indices (%) for the lower section based on vegetation composition and cover over 4 years (1985-1988) for disturbance category comparisons (Basis: 20 subplots for berm, 20 for skidroad surface, and 5 for upper and lower undisturbed categories)

	Unlogged	Undisturbed	Skidroad surface	Berm
Unlogged	0	97	100	99
Undisturbed		0	80	44
Skidroad surface			0	52
Berm				0

Table 17. Average frequency (%) and cover (%) of plants (1985-1988) present in more than 40% of sampled plots, lower section

Species	Undisturbed		Skidroad berm		Skidroad surface	
	Frequency	Cover	Frequency	Cover	Frequency	Cover
<i>Amelanchier alnifolia</i>	65	3	-	-	-	-
<i>Linnaea borealis</i>	42	1	-	-	-	-
<i>Paxistima myrsinites</i>	73	2	-	-	-	-
<i>Rosa nutkana</i>	48	4	43	3	-	-
<i>Shepherdia canadensis</i>	75	6	-	-	-	-
<i>Spiraea betulifolia</i>	92	10	89	8	60	2
<i>Epilobium minutum</i>	58	1	53	1	-	-
<i>Berberis aquifolium</i>	68	2	-	-	-	-
<i>Carex rossii</i>	48	2	60	2	-	-
<i>Ceanothus sanguineus</i>	46	1	54	1	47	1
<i>Oryzopsis asperifolia</i>	48	1	-	-	-	-
<i>Festuca rubra</i> *	-	-	-	-	45	11
<i>Trifolium hybridum</i> *	-	-	58	5	98	6
<i>Festuca occidentalis</i> *	-	-	-	-	53	7
<i>Trifolium pratense</i> *	-	-	-	-	77	5
<i>Epilobium angustifolium</i>	-	-	46	2	-	-
<i>Calamagrostis rubescens</i>	-	-	61	5	-	-

* Operationally seeded

Table 18. General tree root parameters from upper section (in mm)

Parameter	Disturbance category					
	Upper undisturbed	Inner track	Outer track	Berm	Sidecast	Lower undisturbed
----- Lodgepole pine -----						
Ground level diameter	27 a*	25 a	25 a	27 a	25 a	28 a
Solid wood length	49 b	64 ab	73 ab	80 a	68 ab	67 ab
Solid wood width	37 a	30 a	31 a	33 a	31 a	35 a
Root depth	277 abc	252 bc	245 c	309 ab	317 a	272 abc
----- Douglas-fir -----						
Ground level diameter	16 ab	15 b	16 ab	18 ab	17 ab	19 a
Solid wood length	65 a	58 a	59 a	77 a	69 a	70 a
Solid wood width	18 ab	15 b	16 b	19 ab	18 ab	22 a
Root depth	214 ab	194 b	196 b	283 a	254 ab	228 ab

* Means within rows having the same letter are not significantly different at the 0.05 level.

Table 19. Mean root areas (mm²) for excavated trees from the upper section

Layer	Disturbance category					
	Upper undisturbed	Inner track	Outer track	Berm	Sidecast	Lower undisturbed
----- Lodgepole pine -----						
0-10 cm	437 a*	437 a	469 a	613 a	545 a	604 a
10-20 cm	455 b	426 b	517 b	807 a	685 ab	648 ab
20-30 cm	57 a	35 a	39 a	108 a	86 a	54 a
30-40 cm	2 c	2 c	2 c	23 a	18 ab	5 bc
Total	265 a	250 a	348 a	345 a	303 a	240 a
----- Douglas-fir -----						
0-10 cm	126 ab	80 b	94 b	247 a	195 ab	193 ab
10-20 cm	127 ab	85 b	99 b	317 a	240 ab	224 ab
20-30 cm	10 b	2 b	7 b	55 a	24 b	13 b
30-40 cm	1 a	0 a	1 a	8 a	7 a	0 a
Total	90 a	76 a	91 a	130 a	168 a	182 a

* Means within rows having the same letter are not significantly different at the 0.05 level.

Table 20. General tree root parameters from lower section (in mm)

Parameter	Disturbance category		
	Undisturbed	Skidroad surface	Berm
----- Lodgepole pine -----			
Ground-level diameter	34 a*	35 a	35 a
Solid-wood length	81 a	89 a	75 a
Solid-wood width	43 a	45 a	45 a
Root depth	227 b	225 b	268 a
----- Douglas-fir -----			
Ground-level diameter	23 a	22 a	23 a
Solid-wood length	56 a	54 a	63 a
Solid-wood width	24 a	24 a	25 a
Root depth	227 a	225 a	256 a

* Means within rows having the same letter are not significantly different at the 0.05 level.

Table 21. Mean root areas (mm²) for excavated trees from the lower section

Layer	Disturbance category		
	Undisturbed	Skidroad surface	Berm
----- Lodgepole pine -----			
0-10 cm	1088 a*	1065 a	1163 a
10-20 cm	1151 a	1047 a	1329 a
20-30 cm	35 a	69 a	80 a
30-40 cm	2 a	6 a	14 a
Total	889 a	861 a	914 a
----- Douglas-fir -----			
0-10 cm	300 a	220 a	316 a
10-20 cm	316 a	218 a	374 a
20-30 cm	11 b	18 b	50 a
30-40 cm	4 a	1 a	4 a
Total	190 a	162 a	238 a

*Means within rows having the same letter are not significantly different at the 0.05 level.

Appendix 1. By-species ANOVA table

Source of Variation	df	Error
Plot, P	p-1	
Row(Plot), R(P)	$\sum_{i=1}^p (r_i - 1)$	
Disturbance, D	d-1	PxD (for balanced case)*
PxD	(p-1) x (d-1)	
DxR(P)	by subtraction**	
Trees(DxRxP)	$\sum_{i=1}^p \sum_{j=1}^{r_i} \sum_{k=1}^{d_{ij}} (t_{ijk} - 1)$	
Total	n-1	

* linear combination of PxD, DxR(P), and Tree (DxRxP) for unbalanced case.

** Degrees of freedom for DxR(P) are by subtraction

$$(n - 1) - (p - 1) - \sum_{i=1}^p (r_i - 1) - (d - 1) - (p - 1) \times (d - 1) - \sum_{i=1}^p \sum_{j=1}^{r_i} \sum_{k=1}^{d_{ij}} (t_{ijk} - 1).$$

n=total sample size.

p=number of plots.

d=number of disturbance categories.

r_i =number of rows with at least one tree in plot i .

d_{ij} =number of disturbance categories with at least one tree in row j of plot i .

t_{ijk} =number of trees located in disturbance class k of row j in plot i .

Appendix 2. Analysis of variance for parameters for the upper section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Total bulk density					
0-10 cm	2	6	25x10 ⁻²	47.93	0.0002
10-20 cm	2	6	36x10 ⁻²	26.73	0.0010
Fine bulk density					
0-10 cm	2	6	16x10 ⁻³	1.13	0.3841
10-20 cm	2	6	16x10 ⁻²	15.44	0.0043
Coarse fragment content					
0-10 cm	2	6	8x10 ⁻²	12.11	0.0078
10-20 cm	2	6	4x10 ⁻²	4.37	0.0674
Resistance to penetration					
0.0 cm	2	6	1141	10.10	0.0120
2.5	2	6	5955	13.14	0.0064
5.0	2	6	6787	10.18	0.0118
7.5	2	6	17262	12.58	0.0071
10.0	2	6	44208	61.89	0.0001
12.5	2	6.04	72286	17.34	0.0031
15.0	2	6.03	121277	7.84	0.0210
17.5	2	6.04	191565	9.60	0.0133
20.0	2	6.05	260467	11.83	0.0007
Soil chemistry					
0-10 cm					
Organic carbon	2	6	2	4.91	0.0546
Total nitrogen	2	6	3x10 ⁻³	5.02	0.0523
C/N	2	6	17	0.44	0.6649
pH	2	6	4x10 ⁻³	0.48	0.6391
10-20 cm					
Organic carbon	2	6	1	6.39	0.0326
Total nitrogen	2	6	8x10 ⁻⁴	2.07	0.2071
C/N	2	6	68	0.64	0.5600
pH	2	6	2	1.78	0.2478
Soil Moisture					
Lodgepole pine	5	2.99	8x10 ⁻³	48.89	0.0046
Douglas-fir	5	3.72	6x10 ⁻³	5.60	0.0675
Combined	5	3.46	1x10 ⁻²	35.33	0.0040
Lodgepole pine					
5-year tree growth					
Height	5	15.17	1857	1.24	0.3402
Diameter	5	15.15	33	0.36	0.8645

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio

Appendix 2 (continued). Analysis of variance for parameters for the upper section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Lodgepole pine					
10-year tree growth					
Height	5	16.59	3635	0.86	0.5271
Diameter	5	16.48	149	0.65	0.6649
Douglas-fir					
5-year tree growth					
Height	5	15.66	2862	6.01	0.0027
Diameter	5	15.50	77	2.44	0.0808
10-year tree growth					
Height	5	18.96	7915	2.97	0.0379
Diameter	5	16.84	248	1.81	0.1657
Tree Foliage Nutrients					
Lodgepole pine					
N	5	15	7x10 ⁻²	1.05	0.4277
P	5	15	8x10 ⁻³	1.38	0.2868
K	5	15	3x10 ⁻²	2.38	0.0887
Ca	5	15	7x10 ⁻³	2.26	0.1018
Mg	5	15	9x10 ⁻⁴	3.51	0.0266
S	5	15	3x10 ⁻³	1.96	0.1435
Mn	5	15	7033	3.42	0.0293
Total Fe	5	15	1064	1.10	0.4015
Douglas-fir					
N	5	15.09	13x10 ⁻²	3.66	0.0229
P	5	15.09	14x10 ⁻³	8.52	0.0005
K	5	15.11	33x10 ⁻³	1.00	0.4517
Ca	5	15.06	3x10 ⁻³	0.55	0.7383
Mg	5	15.06	2x10 ⁻³	2.88	0.0508
S	5	15.09	4x10 ⁻³	1.62	0.2144
Mn	5	15.09	9369	1.47	0.2582
Total Fe	5	15.14	955	1.36	0.2939
Lodgepole pine root data					
Ground-level diameter	5	15	32	3.63	0.0237
Solid-wood length	5	15	1694	3.67	0.0228
Solid-wood width	5	15	129	1.41	0.2775
Root depth	5	15	20342	5.50	0.0045
Root areas		15			
0-10 cm	5	15	122804	2.00	0.1363
10-20 cm	5	15	473396	5.83	0.0035
20-30 cm	5	15	19017	2.03	0.1317
30-40 cm	5	15	1960	11.95	0.001
Total	5	15	44322	1.19	0.3582

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio

Appendix 2 (continued). Analysis of variance for parameters for the upper section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Douglas-fir root data					
Ground-level diameter	5	15.22	43	4.00	0.0163
Solid-wood length	5	15.17	1241	1.21	0.3505
Solid-wood width	5	15.19	100	4.18	0.0138
Root depth	5	15.24	27646	6.23	0.0025
Root areas					
0-10 cm	5	15.19	95835	4.88	0.0074
10-20 cm	5	15.22	188313	7.86	0.0008
20-30 cm	5	15.35	8271	14.14	0.0001
30-40 cm	5	15.25	312	3.77	0.0202
Total	5	15.22	36326	3.47	0.0272

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio

Appendix 3. Analysis of variance for parameters for the lower section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Total bulk density					
0-10 cm	2	6	35x10 ⁻²	5.61	0.0423
10-20 cm	2	6	69x10 ⁻²	28.26	0.0009
Fine bulk density					
0-10 cm	2	6	20x10 ⁻²	12.57	0.0071
10-20 cm	2	6	22x10 ⁻²	6.95	0.0274
Coarse fragment content					
0-10 cm	2	6	4x10 ⁻²	1.80	0.2436
10-20 cm	2	6	13x10 ⁻²	9.59	0.0135
Resistance to penetration					
0.0 cm	2	6	1349	36.64	0.0004
2.5	2	6	22851	10.63	0.0107
5.0	2	6	45802	14.76	0.0048
7.5	2	6	76424	21.25	0.0019
10.0	2	6	147367	37.44	0.0004
12.5	2	6.01	180508	21.38	0.0019
15.0	2	6.03	189785	31.67	0.0006
17.5	2	6.03	329159	32.14	0.0006
20.0	2	4.03	242178	22.93	0.0063
Soil chemistry					
0-10 cm					
Organic carbon	2	6	1	3.34	0.1059
Total nitrogen	2	6	9x10 ⁻⁴	3.35	0.1053
C/N	2	6	121	3.69	0.0901
pH	2	6	5x10 ⁻³	0.05	0.9488
10-20 cm					
Organic carbon	2	6	3	6.10	0.0358
Total nitrogen	2	6	2x10 ⁻³	7.01	0.0269
C/N	2	6	111	1.66	0.2660
pH	2	6	8x10 ⁻²	0.44	0.6626
Soil Moisture					
Lodgepole pine	2	6	10x10 ⁻³	5.51	0.0438
Douglas-fir	2	6	15x10 ⁻³	6.50	0.0314
Combined	2	6	24x10 ⁻³	15.63	0.0042
Lodgepole pine					
5-year tree growth					
Height	2	6.02	5475	2.09	0.2044
Diameter	2	6.02	176	1.48	0.3009

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio

Appendix 3 (continued). Analysis of variance for parameters for the lower section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Lodgepole pine					
10-year tree growth					
Height	2	6.19	10382	2.20	0.1893
Diameter	2	6.08	1181	2.36	0.1742
Douglas-fir					
5-year tree growth					
Height	2	6.02	2430	1.91	0.2282
Diameter	2	6.03	25	0.77	0.5043
10-year tree growth					
Height	2	6.11	19716	1.13	0.3833
Diameter	2	6.13	1805	2.98	0.1247
Tree Foliage Nutrients					
Lodgepole pine					
N	2	6	16x10 ⁻²	3.18	0.1146
P	2	6	8x10 ⁻⁴	2.37	0.1748
K	2	6	7x10 ⁻³	1.12	0.3859
Ca	2	6	6x10 ⁻³	4.96	0.0535
Mg	2	6	9x10 ⁻⁵	1.84	0.2384
S	2	6	4x10 ⁻³	1.23	0.3567
Mn	2	6	2106	2.71	0.1447
Total Fe	2	6	2612	1.48	0.3002
Douglas-fir					
N	2	6.02	20x10 ⁻³	1.71	0.2586
P	2	6	21x10 ⁻³	7.07	0.0264
K	2	6.01	7x10 ⁻³	0.25	0.7866
Ca	2	6.02	3x10 ⁻³	1.21	0.3614
Mg	2	6.01	5x10 ⁻³	9.07	0.0513
S	2	6.05	7x10 ⁻⁴	1.82	0.2405
Mn	2	6.01	44084	7.04	0.0267
Total Fe	2	6	1326	1.00	0.4216
Lodgepole pine root data					
Ground-level diameter	2	6	1	0.11	0.9013
Solid-wood length	2	6	1177	1.35	0.3279
Solid-wood width	2	6	42	0.64	0.5618
Root depth	2	6	14224	21.62	0.0018
Root areas					
0-10 cm	2	6	63220	0.48	0.6431
10-20 cm	2	6	486779	1.65	0.2683
20-30 cm	2	6	13414	4.81	0.0567
30-40 cm	2	6	921	1.66	0.2668
Total	2	6	16878	0.10	0.9067

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio

Appendix 3 (continued). Analysis of variance for parameters for the lower section by disturbance category

Parameter	Df		MS	F	PR>F
	Num.	Denom.			
Lodgepole pine					
Douglas-fir					
Ground-level diameter	2	6	12	1.58	0.2817
Solid-wood length	2	6	565	1.53	0.2901
Solid-wood width	2	6	15	1.65	0.2679
Root depth	2	6	7230	1.12	0.3866
Root areas					
0-10 cm	2	6	64033	3.83	0.0848
10-20 cm	2	6	150376	2.57	0.1564
20-30 cm	2	6	10511	10.13	0.0119
30-40 cm	2	6	63	1.13	0.3819
Total	2	6	35442	3.10	0.1187

MS=mean square

F=MS(treatment)/MS(error)

PR>F=probability value of F-ratio