Impacts of two stumping operations on site productivity in interior British Columbia

Pacific and Yukon Region — Information Report BC-X-327

R.B. Smith and E.F. Wass

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Cover photo: Mapping temporary ponds.

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Contents

Abstract

Two clearcut sites located in the southern interior of British Columbia, stumped to control root disease in 1980, were studied along with adjacent unlogged and logged but non-stumped portions to determine whether the stumping affected seedling growth, particularly through changes in soil properties. One of the sites (Gates Creek) was located near Vernon in the Moist, Warm Shuswap variant of the Interior Douglas-fir Zone. The other site (Phoenix) occurred in the Moist, Cool Kootenay variant of the Interior Cedar-Hemlock Zone. Two stumping treatments were employed. The first involved stump/root extraction with a bulldozer and brush blade followed by windrowing or piling of the stumps. The second treatment differed in that it also included a final raking with a bulldozer and brush blade to bring more of the broken roots to the surface.

Ground surveys were conducted to determine the type, depth, extent and cause of soil disturbance on stumped and non-stumped portions of the cutovers. Soils associated with major soil disturbance categories were tested for penetrability, bulk density, pH, total nitrogen and organic carbon and these measures compared with "undisturbed" soils, i.e., those with humus intact. Plantations of Douglas-fir (*Pseudotsuga menziesii*) and lodgepole pine (*Pinus contorta* var. *latifolia*) were established at Gates Creek and Douglas-fir and western larch (*Larix occidentalis*) at Phoenix. Trees were thinned after 5 years and a final measurement of heights and diameters made on the residual trees after 8 years. Other measures taken on or around randomly selected trees included plant moisture stress, foliage nutrient content, soil moisture, top and root weights and vegetative composition and cover.

Results were described in terms of area disturbed by each treatment, soil physical and chemical properties and seedling performance. The initially dense and moist soil at the Gates Creek site was more adversely affected by the stumping operations than the relatively loose, dry soil at the Phoenix site. Up to 8 years, tree growth was generally reduced by the stumping disturbance on the Gates Creek site; whereas, stumping without raking was generally favorable to tree growth on the Phoenix site.

Vegetative cover was less on stumped areas than on clearcut but non-stumped areas for up to 5 years at Gates Creek and 3 years at Phoenix. The greater influence of the stumping on vegetation composition and cover at Gates Creek compared with Phoenix is discussed.

Recommendations are made for reducing detrimental effects of stumping particularly on sensitive soils.

Résumé

On a étudié deux zones de coupe rase situées dans le centre-sud de la Colombie-Britannique, dessouchées en 1980 afin de lutter contre la maladie des racines, ainsi que des zones boisées et des aires de coupe non dessouchées adjacentes pour déterminer si le dessouchage influait sur la croissance des semis, notamment en raison des changements des propriétés du sol. L'un des emplacements (ruisseau Gates) se trouvait près de Vernon, dans la variante humide et chaude de la Shuswap située dans la zone intérieure de Douglas taxifoliés. L'autre emplacement (Phoenix) était situé dans la variante humide et fraîche de la Kootenay de la zone intérieure de Cèdres et de Pruches. Deux méthodes de dessouchage ont été employées. Le premier traitement consistait en l'extraction des souches/racines au moyen d'un bouteur et d'une lame à rémanents, puis en la mise en andains ou en l'empilage des souches. Outre ces étapes, le second traitement comportait aussi un dernier râtelage fait à l'aide d'un bouteur et d'une lame à rémanents afin de retirer davantage de racines cassées du sol.

Des levés au sol ont été effectués afin de déterminer le type, la profondeur, l'étendue et les causes des perturbations du sol dans les zones dessouchées et non dessouchées des aires de coupe rase. Pour les principales catégories de perturbations des sols, on a mesuré la pénétrabilité, la densité apparente, le pH et les concentrations d'azote totale et de carbone organique, et on a comparé les mesures avec des valeurs obtenues dans des sols "non perturbés", c'est-à-dire des zones où l'humus était intact.

On a procédé à la plantation de Douglas taxifoliés (*Pseudotsuga menziesii*) et de Pins tordus (*Pinus contorta var. latifolia*) au ruisseau Gates, et de Douglas taxifoliés et de Mélèzes occidentales (*Larix occidentalis*), à Phoenix. On a éclairci les plantations au bout de cinq ans, puis, au bout de huit ans, on a fait une dernière mesure des hauteurs et des diamètres des arbres non coupés. On a aussi mesuré le stress d'humidité, la teneur en éléments nutritifs du feuillage, l'humidité du sol, le poids des cimes et des souches et la composition et l'étendue de la couverture végétale chez des arbres choisis au hasard et autour de ceux-ci.

Le document donne la superficie des terres perturbées par chaque type de traitement, les propriétés physiques et chimiques des sols et le rendement des semis. Le sol au ruisseau Gates qui, au départ, était dense et humide, a été davantage perturbé par le dessouchage que celui à Phoenix, où le sol est relativement meuble et sec. Pendant une période s'échelonnant jusqu'à huit ans, le dessouchage a réduit la croissance des arbres à proximité du ruisseau Gates, tandis que cette opération sans ratissage a généralement été favorable au développement des arbres à Phoenix.

La couverture végétale était moins étendue dans les zones dessouchées que dans les aires de coupe rase non dessouchées pendant une période s'échelonnant jusqu'à cinq ans à proximité du ruisseau Gates et à trois ans à Phoenix. Le document traite des perturbations plus importantes du dessouchage sur la composition et l'étendue de la couverture végétale du ruisseau Gates par rapport à celles de l'emplacement de Phoenix.

On formule des recommandations afin de réduire les effets nuisibles du dessouchage, particulièrement sur les sols vulnérables.

Acknowledgements

We acknowledge with thanks the cooperation of Bob Norman and Gerry Wellburn of Fletcher Challenge Ltd. (formerly Crown Forest Products) with regard to the Gates Creek site located on their Tree Farm License No. 9. Assistance in making fall measurements at the Gates Creek site was provided by both Fletcher Challenge and the Vernon District of the British Columbia Forest Service. We also thank Al Barclay, Resource Officer (Silviculture), British Columbia Forest Service, Boundary District, for his frequent provision of help to sample and measure trees at the Phoenix site. Marvin Grismer (Forestry Canada) helped to coordinate and conduct the very successful planting operations. Foliage analyses were conducted by staff of the Pacific Forestry Centre Chemical Services Laboratory, and soil carbon and nitrogen analyses were conducted by Pacific Soils Analysis Inc., Vancouver. Our thanks also go to Dr. H. Froehlich, Department of Forest Engineering, Oregon State University, Corvallis, and R. Mitchell, Pedologist, British Columbia Ministry of Forests, Kamloops, for external reviews of this paper, S. Glover, Forestry Canada, for his thorough editorial review, and M. Lindal, Forestry Canada, for design and layout.

Introduction

Soil degradation from forestry operations (harvesting and site preparation exclusive of haul roads) in British Columbia reduces annual wood yield an estimated 400 000 m^3, and this amount is increasing by about 50 000 m^3 each year (Utzig and Walmsley 1988). Though the harvesting phase has most impact, certain types of site preparation may have detrimental side effects, particularly where large quantities of soil are displaced. An example is root and stump extraction conducted after clearfelling and prior to planting to control the spread of root disease organisms to new regeneration (Wallis 1976; Morrison 1981; Thies 1984). Controlling root disease by direct application of chemicals to stumps and trees has shown promise but has not reached the operational stage (Thies and Nelson 1987). Stump extraction has been conducted on several hundred hectares in British Columbia over the past 15 years and new areas are being treated as funds become available (J. Beale, British Columbia Forest Service, Vancouver, Personal Communication). There is growing evidence that stumping is effective in reducing the incidence of root disease in regeneration (Bloomberg and Reynolds 1988; Morrison *et al.* 1988) but concerns have been expressed about potential soil damage (Smith 1981; Thies and Russell 1983). Many of these concerns have their basis in studies of impacts of ground skidding operations on tree growth (Smith and Wass 1979, 1980; Wert and Thomas 1981; Carr 1986). It is not likely that such results can be entirely extrapolated to stumping operations though parallels in terms of soil displacement by gouging and depositing of soil during skidroad construction on steep slopes can be found with stump extraction.

The first objective of this study was to characterize soil disturbance resulting from stump extraction and to determine whether the various categories and depths of disturbance had any effects on the growth of planted trees. The second objective was to help define the sensitivity of sites and soils to disturbance, a major consideration in developing operational guidelines aimed at reducing soil degradation. The final objective was to suggest improvements in stumping operations that would reduce soil degradation.

Study Sites

Two study sites were chosen: Gates Creek site and Phoenix site (Figure 1). The Gates Creek site was situated within the upper portion of the Moist, Warm Shuswap biogeoclimatic variant of the Interior Douglas-fir Zone (IDFmw1) (Erikson 1982; Lloyd *et al.* 1990) at about 1150 m elevation. The original stand consisted of 80- to 100-year-old Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco and lodgepole pine (*Pinus contorta* var. *latifolia* Engelm.) and was infested with the root disease *Phellinus weirii* (Murr.) Gilb. In January, 1980, 24 ha were clearcut. Stumps were extracted and windrowed with a bulldozer equipped with a brush blade. A portion of the cutover was also raked using the brush blade to bring large roots to the surface (Figure 2). A third portion was felled and windrowed but stumps were not removed. Windrows were set on fire in the fall of 1980 but they burned incompletely.

The Phoenix site was situated in the Cool Kootenay variant of the Interior Cedar-Hemlock Zone (ICHmk1) (Utzig *et al.* 1986; Lloyd *et al.* 1990) at an elevation of about 1350 m. The original stand consisted of uneven-aged Douglas-fir, lodgepole pine and western larch (*Larix occidentalis* Nutt.) and was infested with *Armillaria ostoyae* (Romagn.) Herink. In the fall of 1980, 5 ha in two parcels were logged. One parcel was immediately stumped, piled and raked with a bulldozer and the other was stumped and piled only. The piles were burned successfully (Figure 3). Residual trees remaining after selective logging in a stand adjacent to the stumped and piled treatment were felled and removed to create a harvested but non-stumped treatment.

Methods

Transect Surveys

Surface soil conditions and vegetative cover were assessed for each treatment using a point-intercept system with points described at 3-m intervals along transects (Smith and Wass 1976). Pre-stumping conditions were estimated by running transects in adjacent uncut stands. Data collected at each point included the following: depth; class – gouge, deposit, mixture, etc.; probable cause – track, rake, scalp (top of soil profile removed by bulldozer blade), etc., of mineral soil disturbance; presence of windrowed material; and vegetative cover.

Soil Characteristics

Bulk density.
Measurement of bulk density was made by soil displacement and estimation of the volume of excavated holes with a sand-cone apparatus (Blake 1965). A total of six replicate measurements of the 0 to 10 cm and the 10 to 20 cm depths of mineral soil were made at representative, selected spots for each category of disturbed soil and in undisturbed soil. Collected soils were dried, sieved and weighed, and density was calculated on the basis of both the total and fine (<2 mm) soil fraction.

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

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

1. pH- potentiometrically in 0.01 M $CaCl_2$ (McMullan 1971).
2. organic carbon- LECO induction furnace (McKeague 1978).
3. total nitrogen- automated semi-micro Kjeldahl (McKeague 1978).

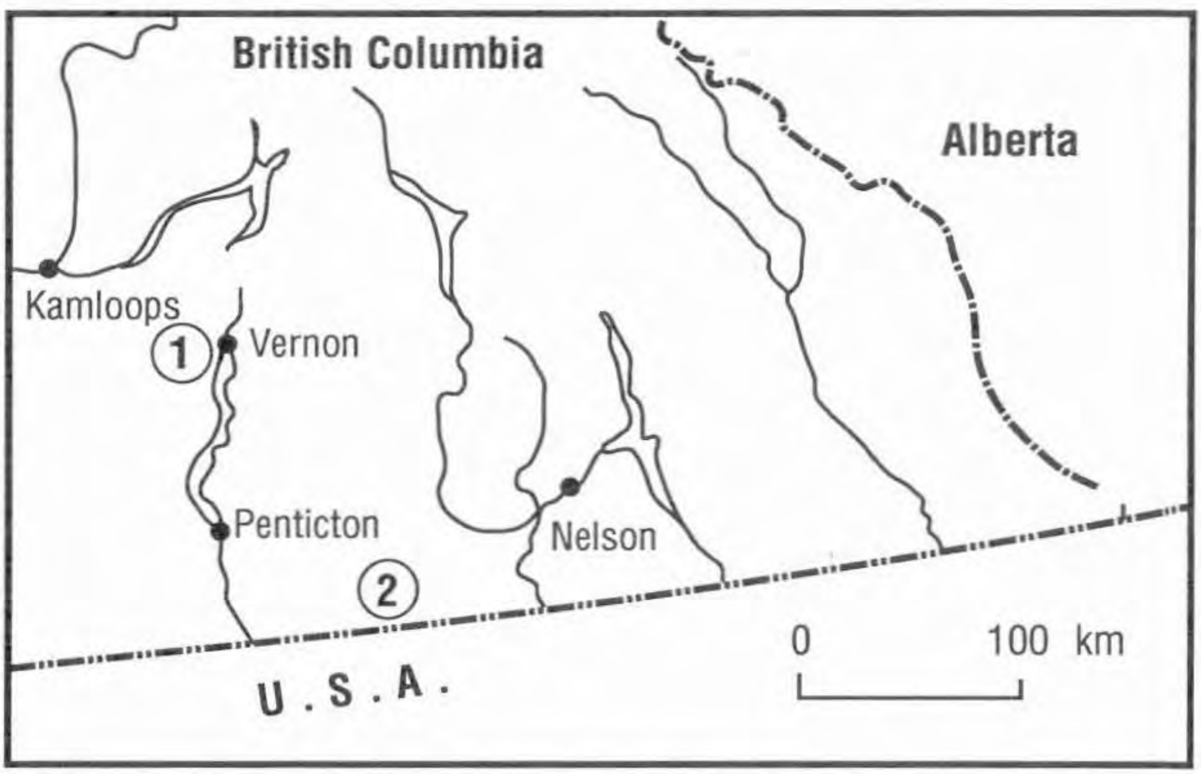

Figure 1. Locations of the Gates Creek (1) and Phoenix (2) study sites.

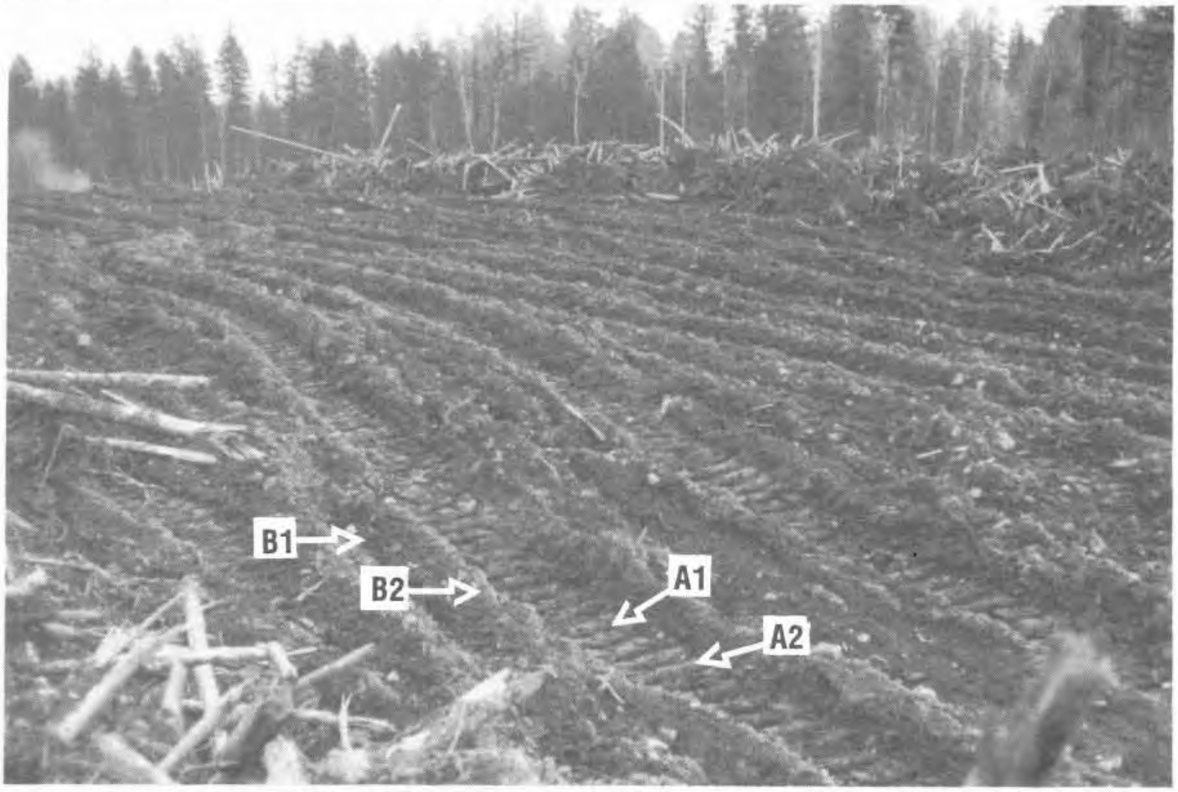

Figure 2. Stumped, windrowed and raked (Raked) treatment at the Gates Creek site. Track: A1 = Lug; A2 = Interlug. Rake: B1 = Bottom; B2 = Top

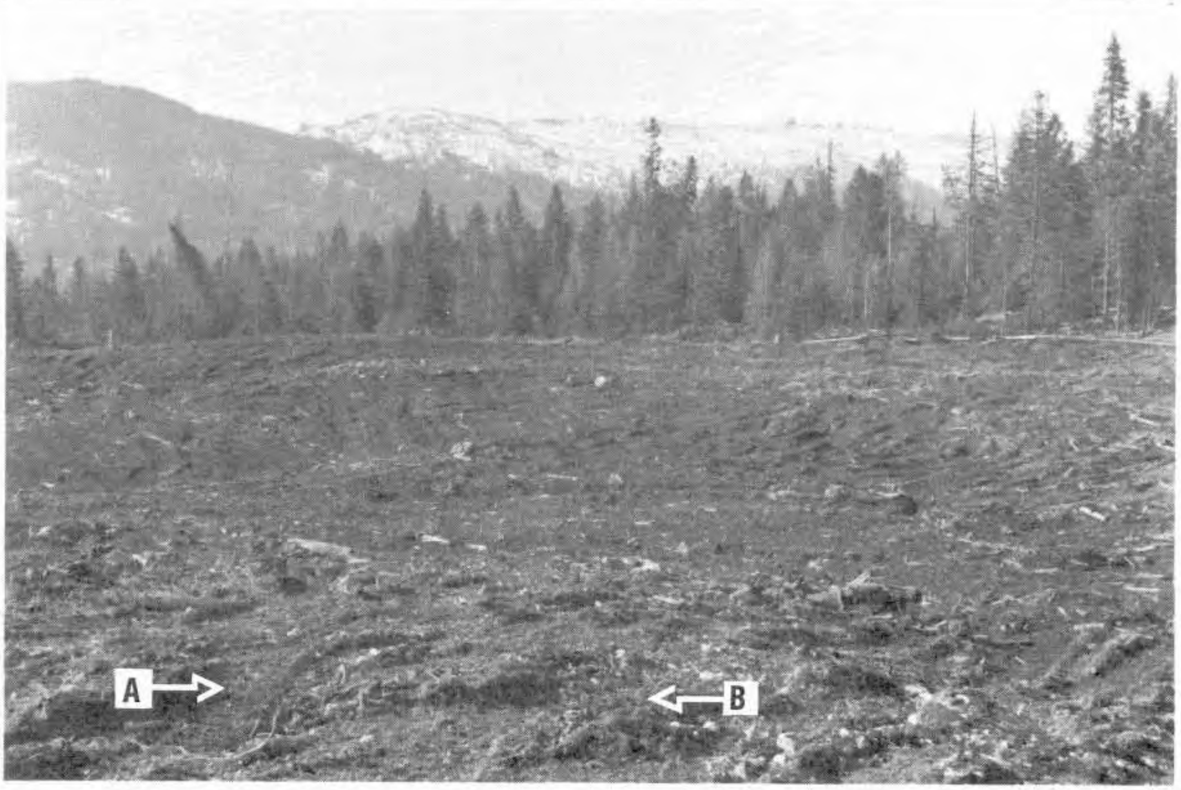

Figure 3. Stumped and piled (Non-raked) treatment at the Phoenix site. A = Track; B = Scalp

Penetrability.

Resistance to penetration was measured close to the bulk density sampling points with an U.S. Corp of Engineers Model CN-973 penetrometer equipped with a 3.2-cm^2 cone. Up to 24 replicated probes were made for major disturbance categories and in undisturbed soil to a depth of 20 cm below the top of the mineral soil. Both the top and bottom of the rake furrows and the lug (portion of track extending beyond the track surface) and interlug impressions of the tracks were tested (see Figures 2,3)

Soil profiles.

Two pits were dug to a depth of about 120 cm at each site in adjacent undisturbed stands. The profiles were described and sampled (Agriculture Canada Expert Committee on Soil Survey 1987; Walmsley *et al.* 1980) and the samples analyzed for particle size and chemistry as described for the bulk density samples. In addition, bulk densities were measured at 10-cm intervals to a depth of 40 cm.

Plantations

Three replicate 20 x 20 m plots were established in each of three treatments at Gates Creek. A total of 200 1+0 styro-plug seedlings each of Douglas-fir and lodgepole pine were planted on each of five major disturbance categories as well as on undisturbed ground for a grand total of 2400 trees for the whole site as follows:

Treatment	Disturbance category
A. Windrowed only (Non-stumped)	1. Undisturbed 2. Track
B. Stumped, windrowed and raked (Raked)	3. Rake 4. Track
C. Stumped and windrowed (Non-raked)	5. Scalp 6. Track

Three plots were established similarly in each of four treatments at Phoenix. A total of 200 1+0 styro-plug seedlings each of Douglas-fir and western larch were planted on six disturbance categories as well as undisturbed ground for a grand total of 2800 trees for the whole site as follows:

Treatment	Disturbance category
A. Harvesting only (Non-stumped)	1. Undisturbed
B. Stumped, piled and raked (Raked)	2. Rake 3. Track
C. Stumped and piled, deep rutting (Non-raked (deep))	4. Scalp 5. Track
D. Stumped and piled, shallow rutting (Non-raked (shallow))	6. Scalp 7. Track

Seedlings were planted with a dibble in the spring of 1982 with row to row alternation of species at a 1-m by 1-m spacing within the constraints of the particular spatial distribution of the disturbance categories. Heights and root collar diameters were measured immediately after planting and annually thereafter each fall up to and including 1986. In early 1987, trees were thinned in all plots to a minimum spacing of 2 m around each tree, leaving about a quarter of the number of original trees, i.e., 40 to 50 per soil disturbance category. To avoid bias, trees were selected for spacing in the office by utilizing a stem map. Competing vegetation was cut down around the spaced trees once each summer from 1987 to 1989. A final measurement was made on the leave trees in the fall of 1989.

Biomass Measurements

Fifty trees of each species were withdrawn from seedling lots for pre-plant biomass measurements. In the fall of 1982, twenty seedlings for each species for each disturbance category were excavated for biomass measurements. In the fall of 1986, after 5 years of growth, 12 trees of each species growing on undisturbed soil and 18 trees of each species for each disturbance category were cut for above-ground biomass measurements. Three trees of each species for each disturbance category were excavated to allow determination of root biomass.

Plant Moisture Stress

In August of the fifth year of outplanting (1986), six trees of each species for each disturbance category, except 12 trees of each species in the undisturbed category at Phoenix, were randomly selected for pre-dawn and mid-day plant moisture stress measurements using a pressure chamber (Waring and

Cleary 1967). Measurements were conducted on freshly cut twigs, one for the pre-dawn and one for the mid-day reading for each tree.

Foliage Nutrients and Needle Weights

Foliage samples of the current year's growth were taken in the fall of 1986 (5 years after outplanting) from six trees per species/disturbance/plot combination for nutrient analysis by the Chemical Services Laboratory at the Pacific Forestry Centre. Trees were the same as those subsequently cut for biomass measurement. After drying, 100 needles of each foliage sample were weighed and then returned to the original foliage sample. After grinding, the six foliage samples from each species/disturbance/plot grouping were combined using equal weights of material from each tree. Chemical analyses were thus done on 36 samples from Gates Creek and 42 samples from Phoenix (three replicates per species/disturbance combination). Samples were dried, ground and then dried again immediately before analyses and digested using a modified method of Parkinson and Allen (1975) (concentrated sulfuric acid and hydrogen peroxide). N and P were analyzed from the original digest on a Technicon Auto Analyzer using the ammonia salicylate reaction for total N and the reduced phospho-molybdate complex for P. The original digest was analyzed for Zn, Fe, Al, Cu and Mn using atomic absorption spectrophotometry. Analysis of S was done directly on the samples with a LECO SC132 sulfur analyzer.

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.

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

Soil Moisture

Soil moisture was measured at depths of 0 to 10 cm and 10 to 20 cm adjacent to the same trees and on the same day sampling was conducted for plant moisture stress. Volumetric moisture content of the top 20 cm of the soil profile was measured with an IRAMS (Instrument for Reflectometry Analysis of Moisture in Soils) (Topp *et al.* 1984) in May and August of 1987 adjacent to nine trees of each disturbance/species combination.

At Gates Creek, ponding of water occurred sporadically in the spring after snow melt throughout many of the plots. The extent of ponding was mapped on April 24, 1985, and the distances from planted trees to surface water was determined.

Vegetation

Characteristics of vegetation by species and layers were measured using procedures outlined by Walmsley *et al.* (1980). Pre-planting vegetation was surveyed on mil-acre (4.05 m^2) plots at each 3-m transect point. Subsequently, estimates were made using tree-centered mil-acre plots at every ninth tree resulting in 18 to 20 plots per disturbance category. In 1982, 1983 and 1984, two assessments were made at each tree, one on a circular plot and the second on a plot of approximately the same area but conforming to the configuration of the particular disturbance. No assessments were made in 1985 and, since it was becoming difficult to delineate disturbance categories on the ground, only circular plots were assessed in 1986.

The degree of similarity in plant cover established on the various disturbance categories was assessed by averaging cover values for species from all plots in each soil disturbance category. The combined species lists and average cover values were then compared between disturbance categories by calculating their dissimilarity (PD) in percent (Pielou 1984, p. 43).

Statistical Analyses

Statistical comparisons were mainly made using ANOVA followed by the Student-Newman-Keuls' multiple range test (Zar 1974; SAS Institute Inc. 1985). Chi-square tests were used to compare soil disturbance levels derived from point-transect surveys and Pearson correlation coefficients for determining significant correlations among plant moisture stress values and tree growth and environmental parameters (SAS Institute Inc. 1985).

Results

Undisturbed Soil Characteristics

Gates Creek
The soil, derived from glacial till, was classified as a Gleyed Eluviated Eutric Brunisol (Agriculture Canada Expert Committee on Soil Survey 1987). Depth of the humus varied from 2 to 10 cm with a pH of 5.6, organic carbon content of 41%, nitrogen content of 1.6% and C/N ratio of 26.

Soil texture was generally a gravelly sandy loam with a clay content (9-13%) at the high limit for sandy loams. The volume of coarse fragments estimated visually on the soil pit walls ranged from 15% at the surface to 30% at depth. Bulk density of the total and fine soil fraction increased from the surface down to 35 cm (Figure 4). Nitrogen and organic carbon content of mineral soil decreased sharply with depth from the surface to 100 cm (Figures 5, 6). Over the same range, the C/N ratio decreased (Figure 7) and pH increased (Figure 8).

Phoenix
The soil, derived from glacial till but with a relatively stone-free capping (possibly aeolian), was classified as an Eluviated Dystric Brunisol (Agriculture Canada Expert Committee on Soil Survey 1987). Depth of humus varied from 6 to 7 cm with a pH averaging 4.2, organic carbon content of 36%, nitrogen content of 1.0% and C/N ratio of 39.

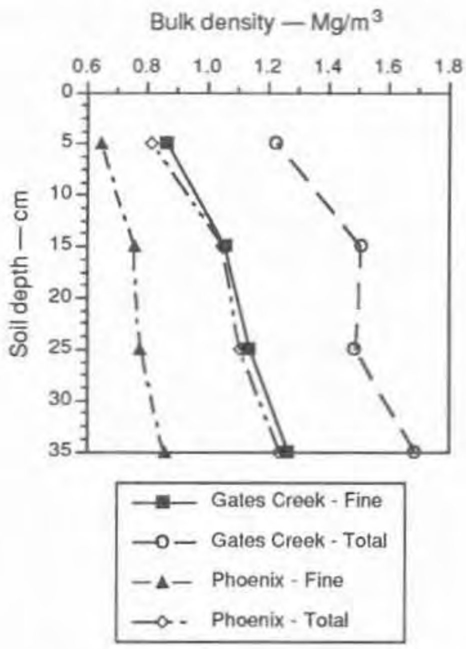

Figure 4. Trends in bulk density with soil depth in undisturbed mineral soil at the Gates Creek and Phoenix sites.

Soil texture was generally a gravelly sandy loam with a clay content (1-4%) at the low end and silt content (37-51%) at the high end of the range for sandy loams. The volume of coarse fragments estimated visually ranged from a low of 2% at the surface of the mineral soil to 45-85% at a depth of 75 cm. Bulk density of the total and fine soil fraction increased with depth from the surface to 35 cm (Figure 4). Nitrogen and organic carbon content decreased with depth from the surface to 100 cm (Figures 5, 6). Over the same range, the C/N ratio decreased (Figure 7) and pH increased (Figure 8).

Areal Extent of Disturbance

Gates Creek
In the uncut stand, 100% of the surface was undisturbed, i.e., the humus was intact. In the non-stumped but windrowed treatment, 32% of the area was classified as undisturbed. Disturbance mainly resulted from bulldozer tracks and log yarding (Table 1). Mineral soil exposure in the raked treatment was 100%. Rakes, tracks, windrows and scalps were major categories. In the non-raked treatment, mineral soil exposure was also 100%; this was due mainly to scalps, tracks and windrows. The amount of very deep disturbance was significantly less (Chi-square test) for the windrowed, non-stumped treatment than either of the stumped treatments.

Phoenix
In the uncut stand, 98% of the points were undisturbed with humus intact, and 2% were undisturbed on exposed roots. In the raked treatment, 100% of the surface was disturbed with mineral soil exposed (Table 2). Major categories of disturbance were tracks, rakes and non-raked scalps. The non-raked area also had 100% mineral soil exposed with the major categories being scalps and tracks. Significantly more (Chi-square test) of the disturbance in the piled, non-raked treatment was classed as very deep than in the raked treatment.

Bulk Density

Gates Creek
There were no significant differences in bulk density among disturbance categories in the raked treatment but all disturbed spots there were significantly denser than the undisturbed mineral soil (Table 3). In the

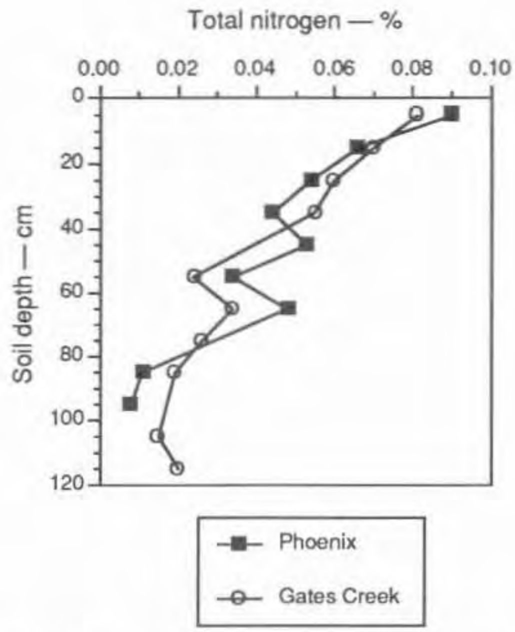

Figure 5. Trends in total nitrogen with soil depth in undisturbed mineral soil at the Gates Creek and Phoenix sites.

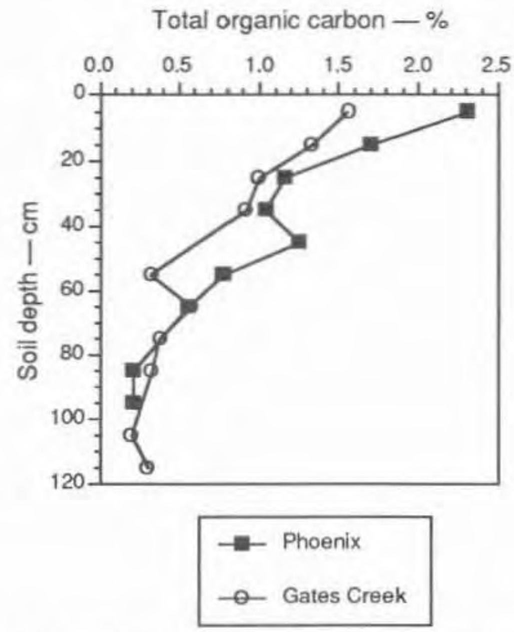

Figure 6. Trends in total organic carbon with soil depth in undisturbed mineral soil at the Gates Creek and Phoenix sites.

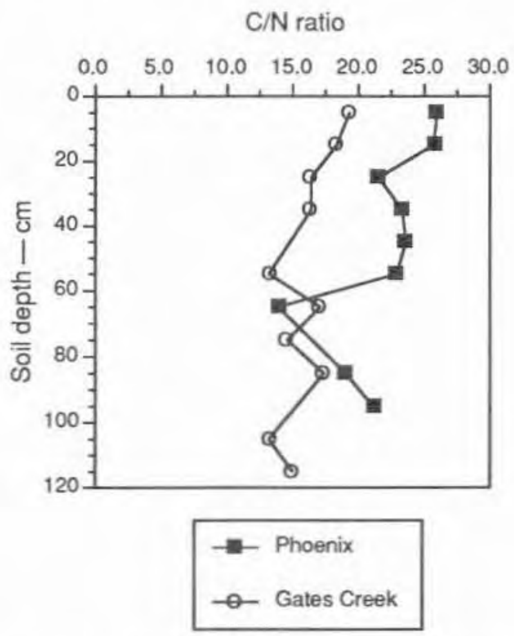

Figure 7. Trends in C/N ratio with soil depth in undisturbed mineral soil at the Gates Creek and Phoenix sites.

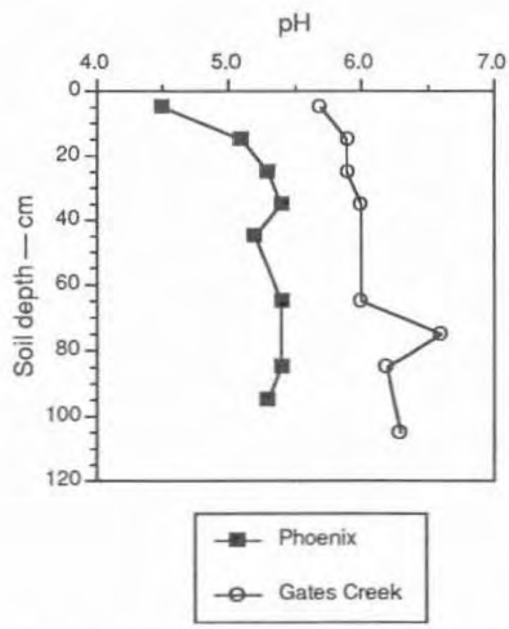

Figure 8. Trends in pH with soil depth in undisturbed mineral soil at the Gates Creek and Phoenix sites.

non-raked treatment, tracks were significantly denser than both the undisturbed soil or scalps, and the latter category was significantly less dense at 10 to 20 cm than the undisturbed soil (Table 3). Densities measured at various depths in gouges (mainly tracks) were greater than those recorded at equivalent depths in the undisturbed soil (Figure 9).

Phoenix

There was little difference between the bulk densities of the rakes and tracks in the raked treatment and the undisturbed mineral soil (Table 4). In the non-raked treatment, deep tracks were significantly denser than scalps or the undisturbed soil. Densities measured at various depths in gouges were not greatly different than those at equivalent depths in the undisturbed soil (Figure 9).

Penetrability

Gates Creek

The top of rakes at the surface (0 cm) did not differ significantly in penetrability from the undisturbed soil (Table 5). The bottom of rakes at the surface and both categories of rakes at depths of 7.5 cm and 15.0 cm were significantly more resistant to penetration than the undisturbed soil. Both the lugs and interlugs of tracks were significantly more resistant to penetration than the undisturbed soil at all depths in the raked (Table 5) and non-raked (Table 6) treatments. Scalps in the non-raked treatment were significantly lower in resistance to penetration than the track components at all depths, and were more resistant to penetration than the undisturbed soil at 15.0 cm (Table 6).

Phoenix

Both categories of rakes at the surface and rake tops at 7.5 cm had significantly lower resistance to penetration than the undisturbed soil (Table 7). At a depth of 15.0 cm, the bottom of the rake had significantly greater resistance to penetration than the undisturbed soil. Unlike the naturally denser soils at Gates Creek, both the lugs and interlugs of tracks had significantly lower resistance to penetration at the surface than the undisturbed soil for raked (Table 7) and non-raked (Table 8) treatments. At greater depths, lugs and interlugs were significantly higher in resistance in 9 of 12 comparisons. Scalps in the non-raked treatment were in most cases significantly less resistant to penetration than both components of tracks at 7.5 and 15.0 cm and the undisturbed soil at the ground surface (Table 8).

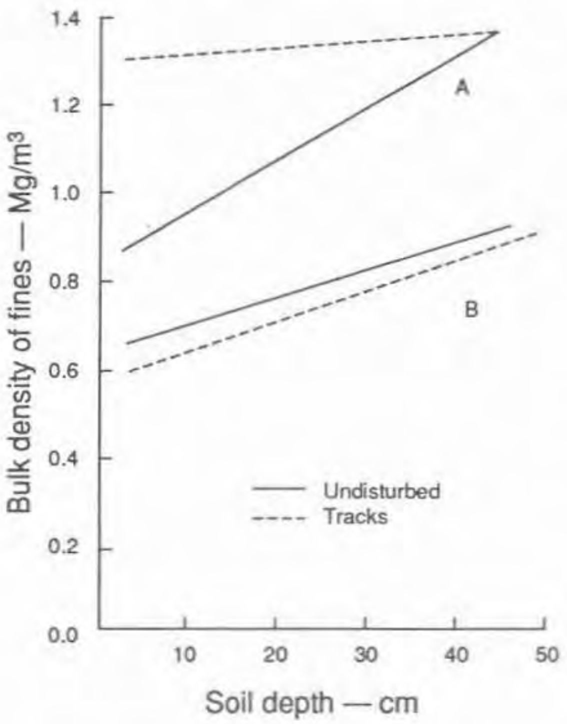

Figure 9. Regressions of fine (< 2 mm) soil bulk densities on soil depth for undisturbed profiles and tracks at the Gates Creek (A) and Phoenix sites (B). From Smith and Wass (1984).

Total Carbon, Total Nitrogen and pH of Bulk Density Samples

There were few significant differences in chemical characteristics of soils despite some large differences in mean values; this was due to large variations in chemical characteristics within disturbance categories. At the Gates Creek site, nitrogen content of mineral soil to a depth of 20 cm was significantly higher in the undisturbed soil than in rakes and tracks in the raked treatment. No significant differences occurred in the non-raked treatment. For some depths of scalps and tracks in the non-raked treatment (both deep and shallow) at Phoenix, nitrogen and carbon contents were higher than in undisturbed soil. Disturbed spots generally had higher C/N ratios in the surface 20 cm than in the undisturbed soil, especially at Phoenix. Disturbed spots had higher pH levels than undisturbed soil at Phoenix but not at Gates Creek. The pH levels were about 0.5 units lower and the C/N ratios 20-30% higher at Phoenix than at Gates Creek.

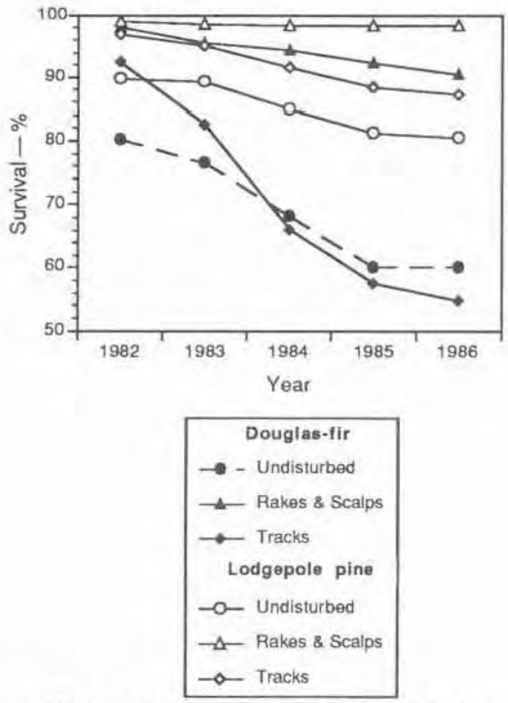

Figure 10. Survival of Douglas-fir and lodgepole pine on disturbed and undisturbed soil at the Gates Creek site for 5 years after planting.

Soil Moisture

Volumetric

In May, 1987, tracks had higher volumetric soil moisture contents than all other disturbance categories including the undisturbed soil at both Gates Creek and Phoenix (Tables 9, 10). Moisture contents were only one-third to one-quarter as high in August of the same year but still were higher in the tracks. The undisturbed and scalp categories at Gates Creek and the undisturbed and rake categories at Phoenix were particularly low in moisture content.

Gravimetric

At Gates Creek, moisture contents measured gravimetrically in August, 1986, were highest at depths of 0 to 10 cm in undisturbed soil, and lowest in rakes and tracks in the raked treatment and scalps in the non-raked treatment (Table 11). No significant differences occurred at depths of 10 to 20 cm. At Phoenix, undisturbed soils at depths of 0 to 10 cm were significantly wetter than rakes at the same depth (Table 12). At depths of 10 to 20 cm, the tracks in the non-raked (deep) treatment were wettest; they were significantly wetter than both the rakes and tracks in the raked treatment.

Tree Survival

Gates Creek

Based on observations to 1986, lowest survival of Douglas-fir occurred on tracks and in undisturbed soil (Figure 10). Considerably higher survival of Douglas-fir occurred on rakes and scalps. Survival of lodgepole pine on tracks and on undisturbed soil was considerably higher than that of Douglas-fir growing on the same disturbance categories. As with Douglas-fir, highest survival for lodgepole pine was on rakes and scalps. The greatest rate of mortality for both species occurred in the third and fourth years after planting

Ponding of water significantly affected tree survival. Survival of both Douglas-fir and lodgepole pine was significantly less in tracks within 1.0 m of the mapped, ponded water (43 and 81%, respectively) than in tracks farther from the water (60 and 92%, respectively).

Phoenix

Survival of both Douglas-fir and western larch to 1986 was more related to treatment than to specific disturbance type or species. Lowest survival of both species occurred in undisturbed soil (Figure 11). There was little difference between survival on tracks and that in rakes and scalps. For both species, the greatest rate of mortality occurred in the third and fourth years after planting.

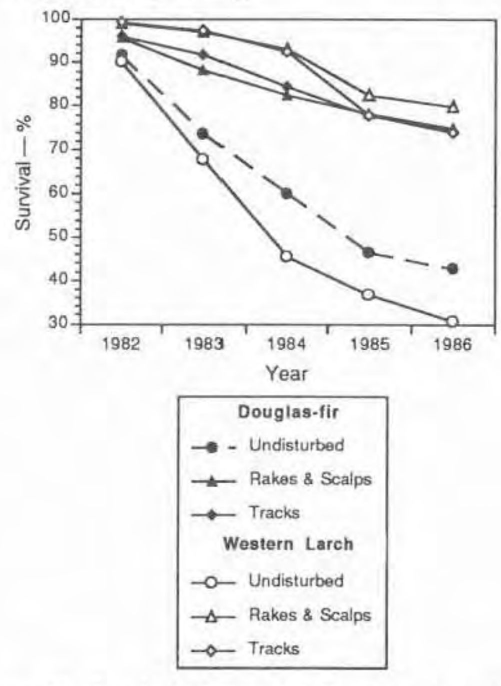

Figure 11. Survival of Douglas-fir and western larch on disturbed and undisturbed soil at the Phoenix site for 5 years after planting.

Tree Growth

Gates Creek

Douglas-fir. After 5 years, Douglas-fir had grown significantly faster in terms of height, diameter and volume on rakes than on tracks in the raked treatment and faster on scalps than on tracks in the non-raked treatment (Table 13). Height growth of trees on undisturbed soil was significantly greater than that in the tracks in the non-stumped treatment. Height growth of Douglas-fir on undisturbed soil was significantly greater than that on all disturbance categories. The superiority of growth of Douglas-fir after 5 years on undisturbed soil was not as well defined for diameter or volume (Table 13; Figure 12). Least growth overall occurred on tracks in both the raked and non-raked treatments (Table 13).

After 8 years, the average height, diameter and volume of Douglas-fir growing in undisturbed soil was greater than for Douglas-fir growing on any of the disturbed spots (Table 13). Differences were significant in comparisons with tracks for height and volume in both raked and non-raked treatments and for volume in the raked treatment.

Relative to seedlings growing on undisturbed soil, both height and volume decreased for Douglas-fir growing on disturbed soil, particularly from the third to the fifth years. On tracks in the raked and non-raked treatments, this downward trend continued strongly to the eighth year (Figure 12). At 8 years,

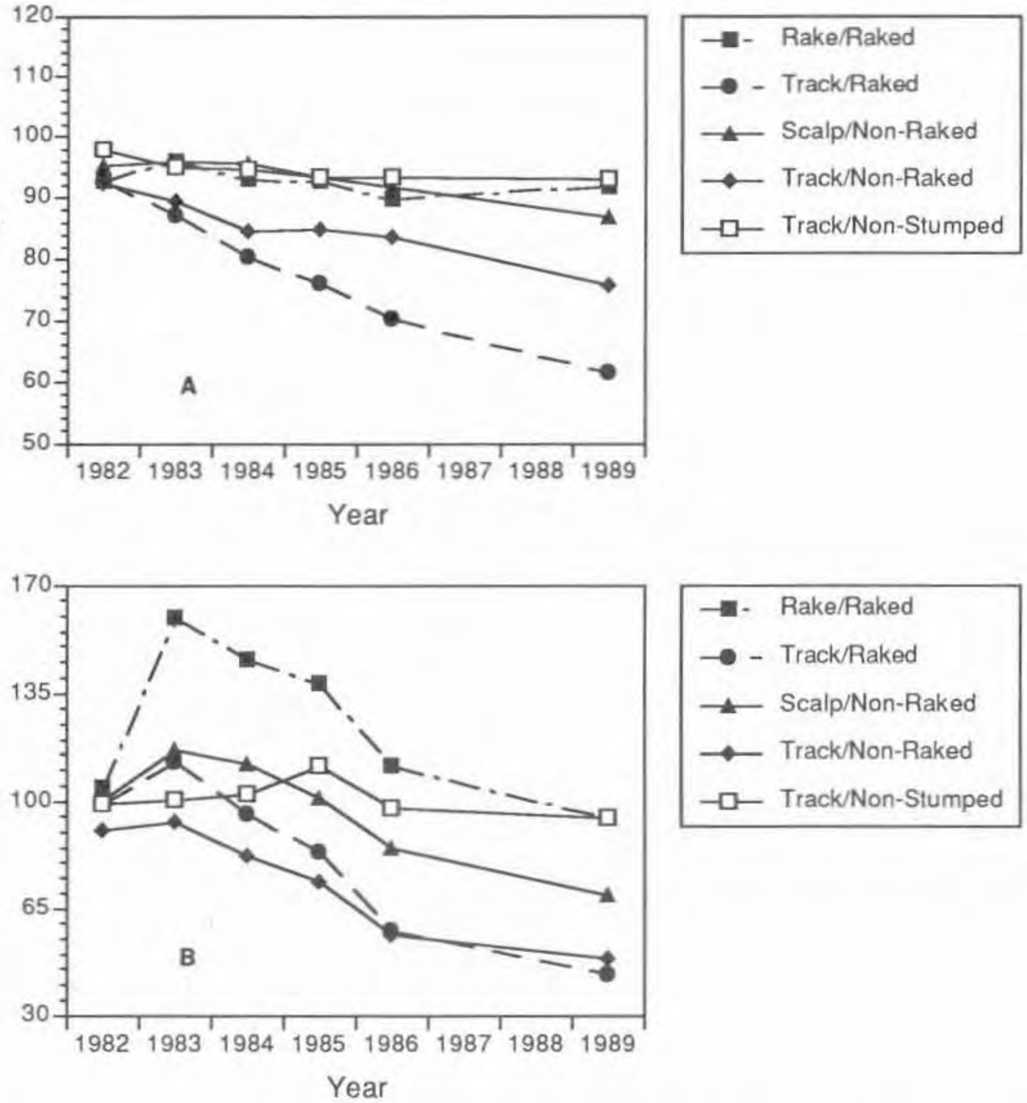

Figure 12. Average height (A) and volume (B) of Douglas-fir growing on five categories of disturbed soil as a percentage of height and volume of Douglas-fir growing on undisturbed soil at the Gates Creek site (1982-89).

average volumes of Douglas-fir on the tracks in raked and non-raked areas were less than 50% of those of trees growing on undisturbed soil (Figure 12).

Lodgepole pine. Height, diameter and volume growth of lodgepole pine at 5 years were all significantly slower on tracks than on rakes in the raked treatment (Table 14). There were no significant differences in these growth measures in the non-raked treatment. In the non-stumped treatment, there were no significant differences between growth of lodgepole pine on tracks and on the undisturbed soil. Best overall growth was on the rakes in the raked treatment and the poorest overall growth was on the undisturbed soil.

After 8 years, the average size of lodgepole pine growing in the undisturbed soil was greater than four (height) and three (diameter and volume) of the five disturbance categories but there were no significant differences.

Relative to the undisturbed areas, heights and volumes of lodgepole pine growing on disturbed spots showed a strong downward trend during the period from 1985 to 1989 after a rapid early start (Figure 13). After 8 years, only trees on rakes and scalps had greater volumes than those growing on undisturbed soil.

Ponding. At 5 years, height and volume of Douglas-fir in the raked treatment and height, diameter and

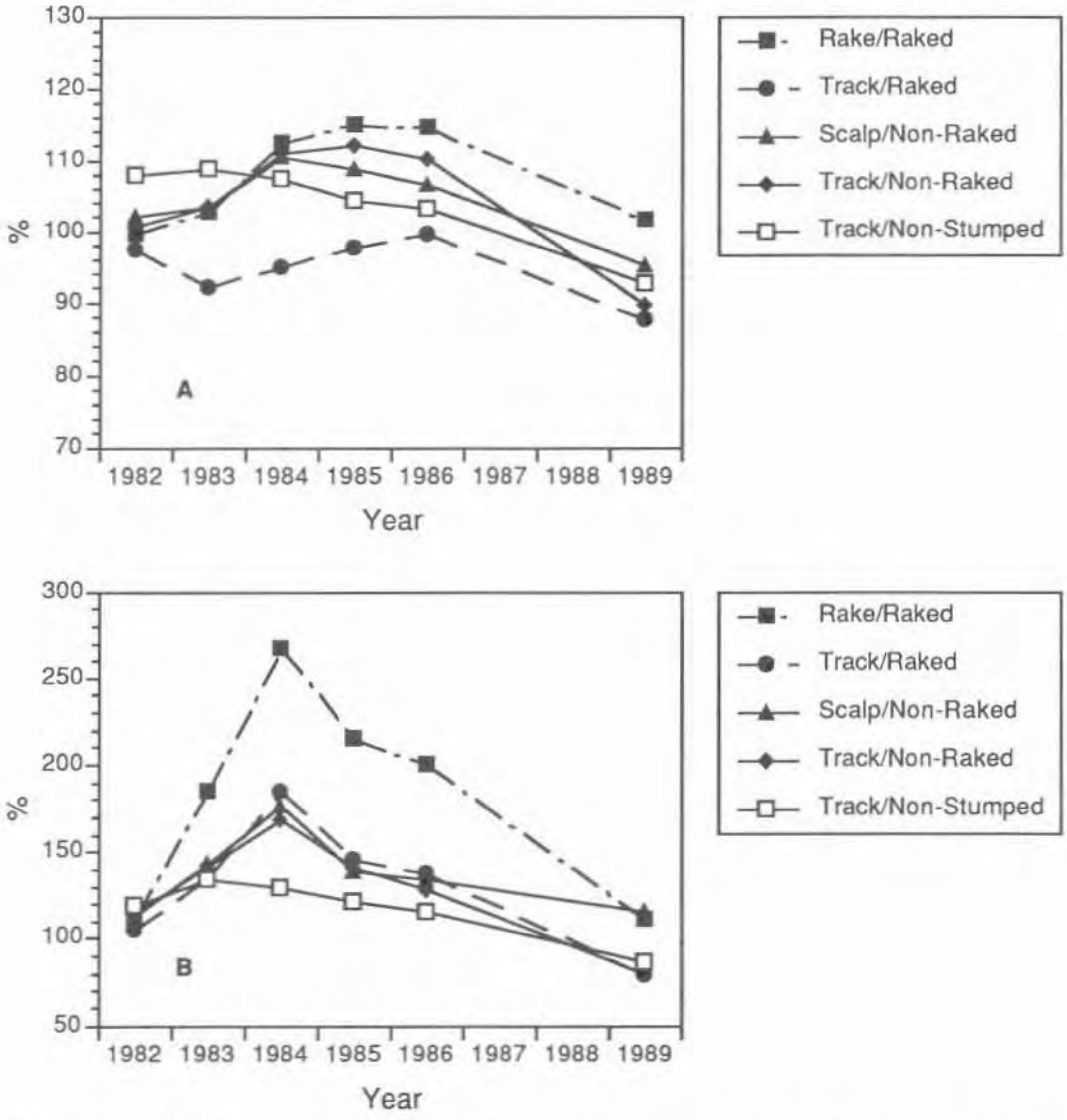

Figure 13. Average height (A) and volume (B) of lodgepole pine growing on five categories of disturbed soil as a percentage of height and volume of lodgepole pine growing on undisturbed soil at the Gates Creek site (1982-89).

volume of Douglas-fir in the non-raked treatment growing in tracks within 1 m of the temporary ponds were significantly lower than those of Douglas-fir growing farther from the ponds (Table 15). The same trends occurred for lodgepole pine in the raked and non-raked treatments but differences were significant only for the raked treatment.

After 8 years, proximity of planted trees to temporarily ponded water still had deleterious effects on growth (Table 15). Combining tracks from all treatments, the height of Douglas-fir growing on tracks and less than 1 m from mapped ponded water was only 71%, diameter only 77%, and the volume only 35% of that of Douglas-fir growing farther from the ponds. All differences were statistically significant. The average height, diameter and volume of lodgepole pine growing near the water was also less, but differences were significant only for volume.

The negative impact of excess water on growth of Douglas-fir was also indicated by the significant negative correlation (Pearson correlation coefficients) between gravimetric moisture in August, 1986, of the 10 to 20 cm soil layer and measures of height, diameter and volume at 5 years. In contrast, lodgepole pine growth increased with increasing August, 1986, gravimetric moisture in the 10 to 20 cm layer. Diameter growth of lodgepole pine did, however, show a negative correlation with gravimetric moisture at 0 to 10 cm.

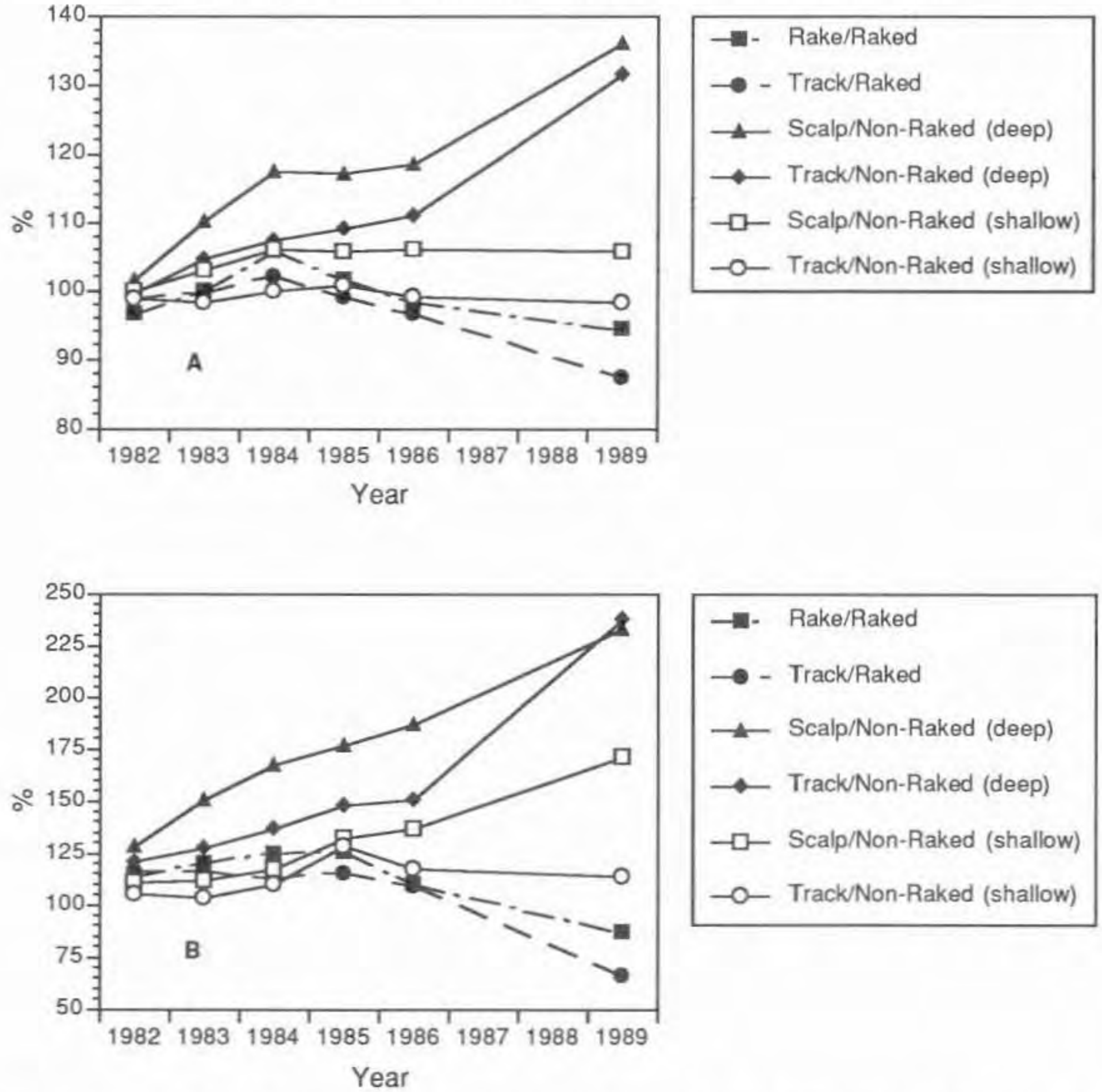

Figure 14. Average height (A) and volume (B) of Douglas-fir growing on six categories of disturbed soil as a percentage of height and volume of Douglas-fir growing on undisturbed soil at the Phoenix site (1982-89).

Phoenix

Douglas-fir. After 5 years, growth of Douglas-fir on rakes and tracks on the raked treatment was not significantly different (Table 16). In the two non-raked treatments (shallow and deep), growth was greater on the scalps than on the tracks, and the differences were significant for all three growth measures in the non-raked (deep) treatment. Best overall growth occurred on scalps in the non-raked (deep) treatment and the slowest growth occurred in the undisturbed soil and on the tracks and rakes in the raked treatment.

After 8 years, Douglas-fir growing on the undisturbed soil were generally smaller than those growing on disturbed spots except for tracks and rakes in the raked treatment (Table 16). Douglas-fir growing on scalps and tracks in the non-raked (deep) treatment were significantly larger than those on undisturbed soil.

Relative to Douglas-fir growing on undisturbed soil, height and volume of Douglas-fir growing on disturbed soil in the non-raked treatment generally increased over the first 5 years, and increased even more sharply in the last 3 years (Figure 14). In the raked treatment, height and volume of Douglas-fir decreased in the fifth year relative to trees on undisturbed soil, and this decrease continued to the eighth year.

Western larch. After 5 years, there were no significant differences in growth of western larch between tracks and rakes in the raked treatment, or between tracks and scalps in the non-raked (shallow) treatment (Table 17). In the non-raked (deep) treatment, height growth was significantly greater for larch growing on scalps than on tracks. Average volume was also higher for larch on scalps in this treatment, but the difference was not significant. Best overall growth occurred on scalps in the non-raked (deep) treatment, and the poorest overall growth occurred on the tracks and rakes in the raked treatment .

After 8 years, the average height and volume of western larch growing on undisturbed ground was less than that of trees growing on all other disturbance categories except rakes and tracks in the raked treatment (Table 17). The best growth occurred on scalps in the non-raked (deep) treatment.

Heights and volumes of larch on the non-raked treatments increased over the last 5 years relative to trees on undisturbed soil (Figure 15). Heights and volumes of larch growing in the raked treatment have also increased in the last 3 years relative to trees on undisturbed soil, but this increase has been slower than in the non-raked treatments.

A significant, positive correlation (Pearson correlation coefficients) occurred between gravimetric moisture content in August, 1986, of the 10-20 cm soil layer and each of height, diameter and volume of western larch at 5 years.

Biomass

Gates Creek

Total dry weights of the above-ground portions of sampled Douglas-fir were not significantly different among the disturbance categories at the end of one growing season (Table 18). After 5 years, however, weights were significantly greater on scalps in the non-raked treatment than on tracks in both the raked and non-raked treatments. In a subsample of these trees, greatest root weights occurred on the scalps in the non-raked treatment and the lowest root weights occurred on tracks in the non-stumped treatment, but differences were not significant.

Mean 100-needle weights (based on all Douglas-fir sample trees) were highest for trees on the undisturbed soil and on tracks in the non-stumped treatment, but differences were not significant.

At the end of one growing season, total above-ground dry weights of sampled lodgepole pine trees were significantly lower on undisturbed soil than on rakes and tracks in the raked treatment and on scalps in the non-raked treatment (Table 18). After 5 years, the mean above-ground weight of lodgepole pine on rakes was significantly greater than for trees on all other disturbance categories except scalps. The mean above-ground weight of lodgepole pine growing on undisturbed soil was significantly less than for trees on all other disturbance categories except for tracks in the non-stumped treatment. In a subsample of these trees, highest dry root weights occurred on rakes, and lowest dry root weights occurred in the undisturbed soil and on tracks in the non-stumped treatment, but differences were not significant.

The mean 100-needle weight of lodgepole pine growing on scalps was significantly greater than for trees on tracks in the raked treatment.

Phoenix.

Total above-ground dry weights of tops of sampled Douglas-fir trees were not significantly different among disturbance categories after one growing season (Table 19). After 5 years, weights were significantly higher on scalps in the non-raked (deep) treatment than for all other disturbance categories. In a subsample of trees cut after 5 years, mean root weight was highest for trees on scalps and lowest for trees on tracks in the non-raked (deep) treatment, but differences were not significant.

The 100-needle weights for Douglas-fir were highest for trees growing in the undisturbed soil and on scalps in the non-raked (deep) treatment and lowest for trees on tracks in the raked treatment and on scalps in the non-raked (shallow) treatment, but differences were not significant.

Total weights of tops of sampled western larch trees after one growing season were not significantly different among the disturbance categories (Table 19). After 5 years, the highest mean top weight occurred for trees on tracks in the non-raked (shallow) treatment and the lowest occurred on tracks in the raked treatment, but differences were not significant. In a subsample of these trees, root weights were highest for trees on scalps and lowest on tracks in the non-raked (shallow) treatment, but differences were not significant.

Mean 100-needle weights of western larch were highest for trees on tracks and scalps in the non-raked (deep) treatment and lowest for trees on tracks in the raked treatment and on scalps in the non-raked (shallow) treatment, but differences were not significant.

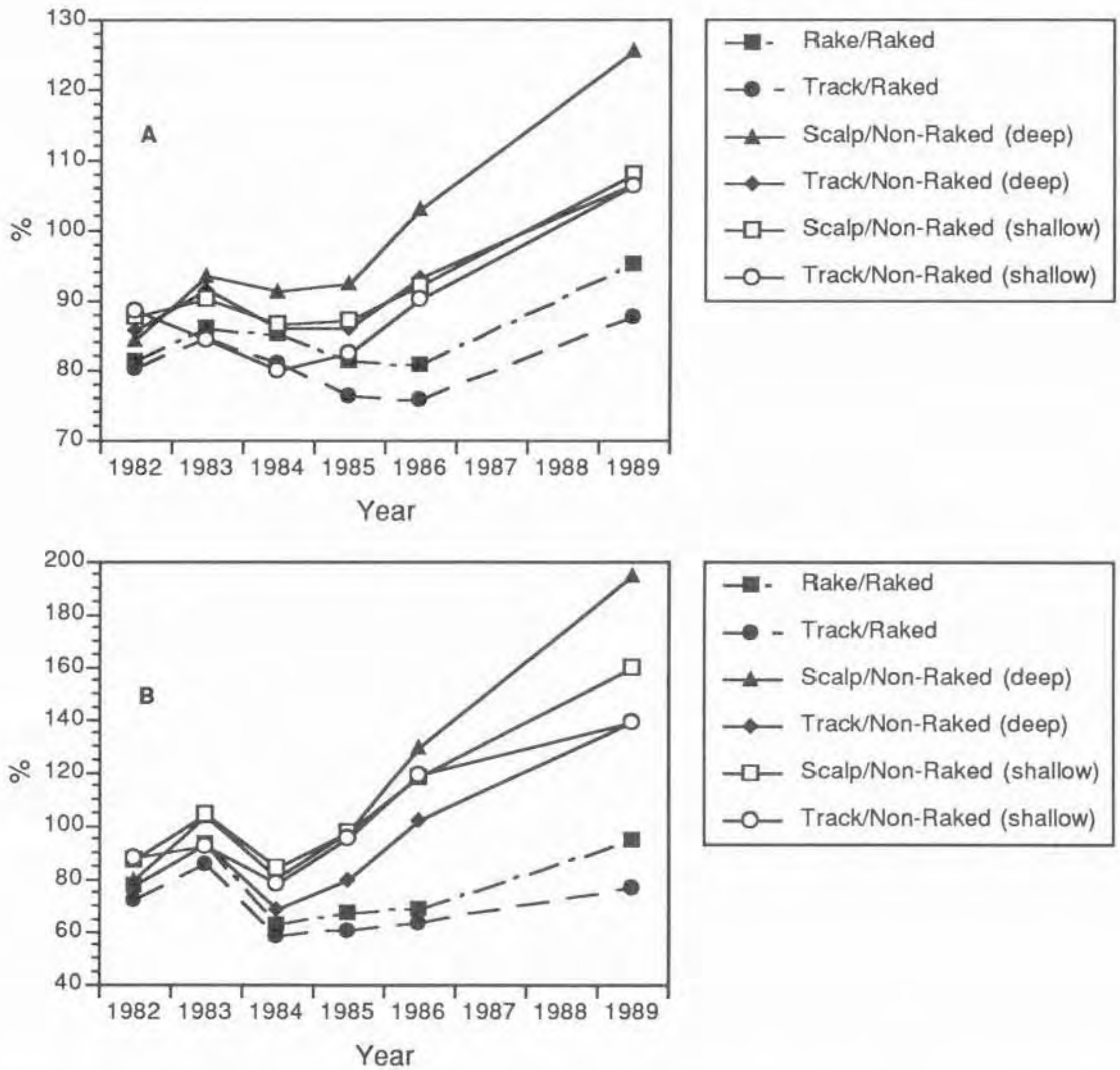

Figure. 15. Average height (A) and volume (B) of western larch growing on six categories of disturbed soil as a percentage of height and volume of western larch growing on undisturbed soil at the Phoenix site (1982-89).

Foliage Nutrients

Gates Creek

Foliage nutrient contents averaged for each of the three treatments are displayed in Table 20. For Douglas-fir, significantly lower contents of Fe and P occurred in the non-stumped treatment than in the raked or non-raked treatments. For lodgepole pine, significantly lower N occurred in the foliage of trees in the non-stumped and raked treatments than in the non-raked area, significantly lower Mg was found in the non-stumped than in the raked treatment, and significantly lower Fe was found in the non-stumped than in the raked and non-raked treatments.

Following the evaluation program of Ballard and Carter (1986), N was determined to be the most deficient element. Very severe deficiencies of this element were diagnosed for Douglas-fir on tracks in both the raked and non-raked treatments and severe deficiencies occurred for trees on all other disturbance categories. Slight deficiencies of Mg and potential nitrogen-induced deficiencies of S were indicated for trees on several disturbance categories. Severe deficiencies in N were noted for lodgepole pine on tracks and rakes in the raked treatment and on tracks and undisturbed soil in the non-stumped treatment. Slight to moderate deficiencies in N were indicated for lodgepole pine on tracks and scalps in the non-raked treatment. Slight deficiencies in P were noted for all disturbance categories as were deficiencies or potential nitrogen-induced deficiencies in S.

Phoenix

Significantly greater N and S concentrations occurred in the foliage of Douglas-fir in the non-stumped treatment than in the raked treatment (Table 21). There was significantly more Mn in Douglas-fir foliage in the non-stumped treatment than in the raked, non-raked (deep) and non-raked (shallow) treatments. For western larch foliage, N and K contents were significantly higher in the non-stumped treatment than in the other three treatments and Na contents were significantly higher in the raked treatment than in the non-stumped and non-raked (shallow) treatments.

Using the program of Ballard and Carter (1986), very severe deficiencies of N were noted for Douglas-fir on both tracks and rakes in the raked treatment, and severe deficiencies of N were noted on tracks and scalps in the non-raked (deep) treatment and on scalps in the non-raked (shallow) treatment. Adequate supplies of N were indicated in foliage on tracks in the non-raked (shallow) treatment and in the undisturbed soil. A slight deficiency in P was found on rakes and tracks in the non-raked (shallow) treatment and some deficiency or potential nitrogen-induced deficiency of S was found in all categories except the undisturbed soil. No deficiencies in any of the tested elements were indicated for Douglas-fir growing in the undisturbed soil.

No deficiency criteria were given by Ballard and Carter (1986) for western larch.

Plant Moisture Stress

Gates Creek

The lowest moisture stress in Douglas-fir, as indicated by pre-dawn measurements, occurred in trees growing on tracks in the non-stumped treatment (Table 22). Levels reported for these trees were significantly lower than for trees growing on tracks in the raked and both tracks and scalps in the non-raked treatments. Pre-dawn stress levels were also low for trees on the undisturbed soil, significantly lower than for trees on tracks in the raked treatment and on scalps in the non-raked treatment. Greatest stress at mid-day occurred in trees growing on scalps and the least stress occurred in trees in the non-stumped treatment and on rakes. The mean value for trees on scalps was significantly higher than those for all other disturbance categories except for tracks in the raked treatment.

A significant negative correlation (Pearson correlation coefficients) occurred between pre-dawn moisture stress and both current diameter growth of Douglas-fir and August gravimetric moisture content of the 0 to 10 cm soil layer. Mid-day moisture stress of Douglas-fir increased significantly with decreasing gravimetric moisture content of both the 0 to 10 cm and 10 to 20 cm soil layers.

The lowest pre-dawn moisture stress for lodgepole pine occurred on tracks in the non-raked treatment and the highest stress occurred on tracks in the raked treatment, but differences were not significant (Table 22). Mid-day readings indicated lowest stress for trees on rakes and highest stress on scalps, but again differences were not significant. Pearson Correlation tests showed no significant correlations between moisture stress and tree growth or gravimetric soil moisture.

Phoenix

The lowest pre-dawn moisture stress for Douglas-fir was recorded on tracks in the non-raked (deep) treatment and the highest stress was on scalps in the non-raked (shallow) treatment but there were no significant differences (Table 23).

At mid-day, the lowest stress occurred in trees growing on the undisturbed soil and the highest stress occurred on tracks in the non-raked (shallow) treatment, but again differences were not significant (Table 23).

Pre-dawn moisture stress values for Douglas-fir increased significantly (Pearson's tests) with decreasing August gravimetric moisture content of both the 0 to 10 cm and 10 to 20 cm soil layers.

For western larch, the lowest pre-dawn stress occurred in trees growing on tracks in the non-raked (deep) treatment and the highest stress occurred in trees on tracks in the non-raked (shallow) treatment, but differences were not significant (Table 23). Lowest stress at mid-day occurred in the undisturbed soil and the highest stress occurred on rakes, but differences were not significant.

Height, diameter and volume growth of western larch at 5 years decreased significantly (Pearson's test) with increasing pre-dawn and mid-day moisture stress. Especially low growth rates were associated with pre-dawn values over -1 MPa and with mid-day values over -2.5 MPa.

Vegetative Cover

Gates Creek

Total vegetative cover in adjacent uncut stands averaged 73% (Figure 16). The tree layer was dominant in terms of height but contained many gaps with a resultant cover of only 33%. Shrub cover was 51% and the herb and moss layers totalled 27%. Douglas-fir and lodgepole pine were the major tree species. The most frequent ground cover consisted of *Paxistima myrsinites*, *Symphoricarpos albus*, *Arnica cordifolia*, and *Disporum hookeri*.

Average total vegetative cover in the first year after stumping (1981) was 5% for both the raked and non-raked treatments, and 30% for the non-stumped treatment (Figure 16). The most frequent plants were *Spiraea betulifolia* and *Arnica cordifolia* on both the raked and non-raked treatments, and *Spiraea betulifolia*, *Paxistima myrsinites*, *Rosa gymnocarpa*, *Arnica cordifolia* and *Thalictrum occidentale* on the non-stumped treatment.

By 1982, total cover on the raked area reached 15%. Within the raked treatment, cover on rakes was about twice that on tracks (Figure 17). Total cover on the non-raked treatment increased more rapidly than on the raked area, and there was higher cover on the scalps than on the tracks in these two treatments (Figures 16, 17). On the non-stumped treatment, cover doubled from 1981 to 1982 and remained well above that of the two stumped treatments (Figure 16). Similar covers occurred on the undisturbed spots and on tracks in the non-stumped treatment (Figure 17), but with a lower complement of shrubs on the latter.

By 1983, total cover on the raked area had increased to 38% but still remained well below that occurring on the non-raked treatment (Figure 16). By this time, in the raked treatment, vegetative cover on the tracks and on the rakes was almost the same (Figure 17). On the non-raked treatment, cover was slightly higher on scalps than on tracks. Cover remained highest on the non-stumped plots (Figure 16).

By 1984, total cover on the raked area increased only slightly, and there were no differences between tracks and rakes (Figures 16, 17). On the non-raked treatment, total cover decreased slightly and there were no differences between tracks and scalps. Cover remained highest on the non-stumped treatment and, within this treatment, cover was greater on tracks than on the undisturbed soil.

By 1986, total cover increased only marginally in the raked and non-raked treatments and decreased markedly in the non-stumped treatment to a point where it was only slightly higher than in the non-raked treatment (Figure 16).

The average cover of dominant plants, i.e., those occurring in over 40% of plots over the period 1982-84, were compared by disturbance categories (Table 24). Dominant only on the non-stumped treatment (undisturbed and tracks) were *Symphoricarpos albus*, *Calamagrostis rubescens*, *Thalictrum occidentale*, *Fragaria vesca and Fragaria virginiana*. *Paxistima myrsinites* and particularly *Spiraea betulifolia* and *Arnica cordifolia* thrived in all disturbance categories, including the non-stumped undisturbed soil and tracks. A number of species were dominant only in the stumped treatments, notably *Rubus parviflorus*, *Rosa gymnocarpa*, *Epilobium angustifolium*, *Epilobium minutum*, *Carex rossii* and *Trifolium repens*.

In paired comparisons, the greatest dissimilarity (96%) in vegetation composition and cover occurred during the first year of measurement between tracks in the raked treatment and the undisturbed soil. The least dissimilarity (32%) occurred in the third year of measurement between tracks and undisturbed soil in the non-stumped treatment. There was a general decrease in dissimilarity for paired comparisons with time (Figures 18, 19). Soil disturbance generally produced greater differences in plant cover at Gates Creek than at Phoenix.

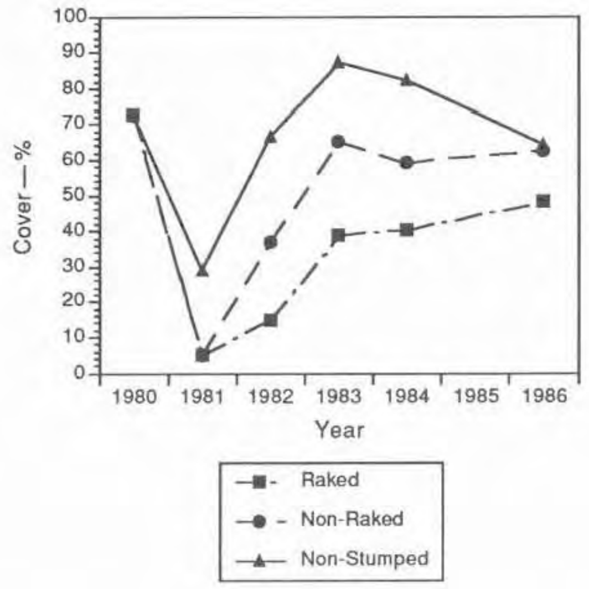

Figure 16. Total percentage cover of vegetation before and for 5 years after harvesting and stumping for three treatment types at the Gates Creek site.

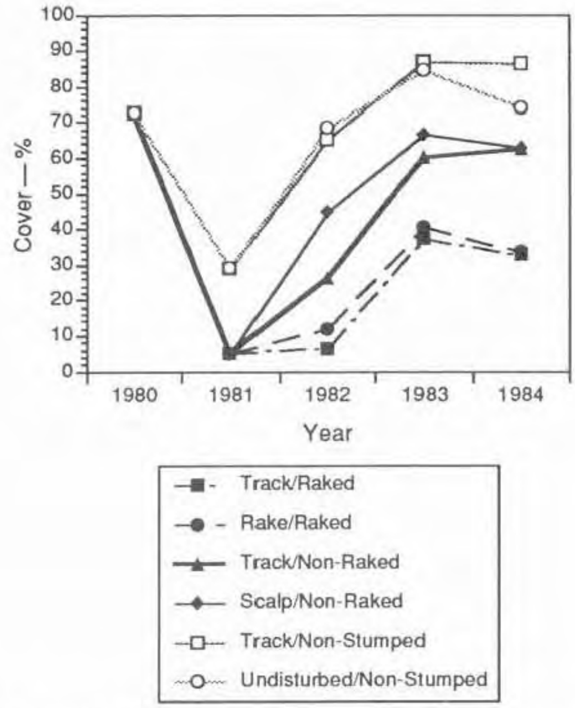

Figure 17. Total percentage cover of vegetation before and for 3 years after harvesting and stumping for the undisturbed soil and five categories of disturbance at the Gates Creek site.

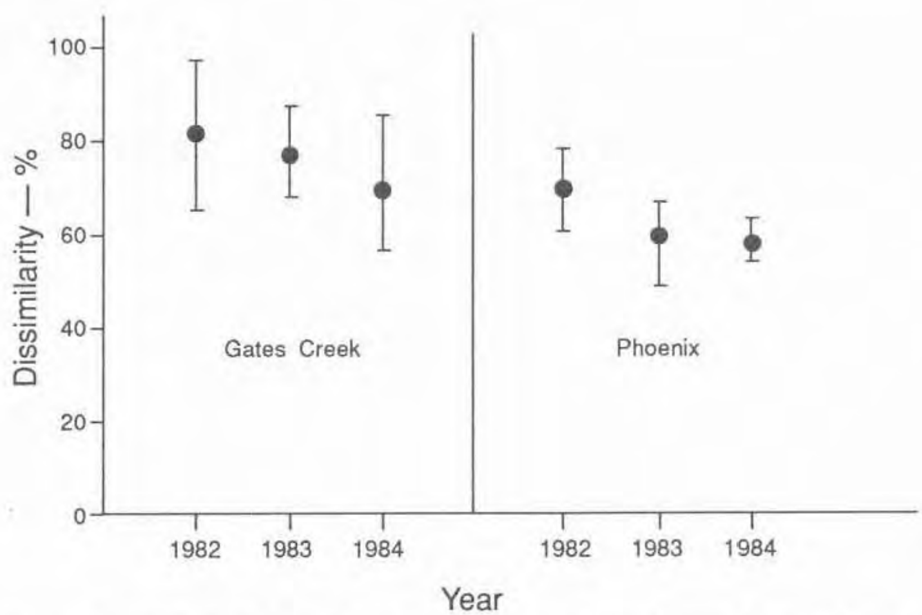

Figure 18. Average dissimilarity indices for vegetation composition and cover for paired comparisons of disturbed and undisturbed soil at the Gates Creek and Phoenix sites for 3 years. Range bars represent extremes for specific disturbance category/undisturbed soil comparisons.

Phoenix

Vegetative cover in unlogged stands adjacent to the stumping areas averaged 76% consisting of 31% cover for trees, 28% cover for shrubs, and 44% cover for herbs and mosses. Layers overlapped considerably. The only tree present in more than 40% of the plots was Douglas-fir. Shrubs present in more than 50% of plots were *Paxistima myrsinites, Linnaea borealis, Lonicera utahensis* and *Chimaphila umbellata*. Grass spp. were present in 74% of the plots.

Mean cover on both the raked and non-raked, stumped portions the first summer after stumping (1981) was 4% (Figure 20). *Fragaria virginiana* and grass spp. were found in more than 50% of the raked plots and in more than 30% of the non-raked plots.

By 1982, total vegetative cover had increased sharply on the raked treatment and on both the non-raked (deep) and non-raked (shallow) treatments (Figure 20). Cover was marginally but consistently higher on tracks than on scalps or rakes in the same treatment (Figure 21). Cover was highest in the non-stumped treatment (Figure 20).

By 1983, total cover in the raked treatment and in both the non-raked (deep) and non-raked (shallow) treatments had continued to increase sharply (Figure 20). Cover remained consistently higher on tracks than on rakes or scalps within the same treatment (Figure 21). Cover remained highest in the non-stumped treatment but with a decreased margin over the stumped treatments (Figure 20).

By 1984, total cover in the raked treatment was highest of all treatments including the non-stumped, which had decreased to 75% (Figure 20). Greater cover of vegetation again occurred on tracks than on rakes or scalps within the same treatment (Figure 21).

By 1986, total cover had been reduced in all treatments with little difference among them (Figure 20).

The average cover of dominant plants, i.e., those present in more than 40% of plots over the period 1982-84, are compared by disturbance categories in Table 25. Several plant species played a dominant role only on undisturbed ground in the non-stumped treatment. Those with the highest cover and frequency were *Lonicera utahensis, Linnaea borealis, Arctostaphylos uva-ursi* and *Antennaria racemosa*. Three species dominant on all disturbance categories including the undisturbed soil were *Calamagrostis rubescens, Fragaria vesca* and *Fragaria virginiana*. This was in contrast to the Gates Creek site in which these same three species dominated only in the non-stumped treatment. *Carex rossii, Carex concinoides, Rumex acetosella, Bromus vulgaris* and *Galium triflorum* were found frequently only on disturbed categories in the stumped treatments.

In paired comparisons, dissimilarities in plant composition and cover between disturbed and undisturbed categories were less marked than at Gates Creek (Figure 18). Also, dissimilarities between scalps and tracks in the non-raked treatment (deep and shallow) and between rakes and tracks in the raked treatment were considerably less than in the non-raked and raked treatments at the Gates Creek site (Figure 19).

In general, higher covers on tracks than on rakes or scalps was caused by greater herb and moss cover. In contrast, shrub cover was generally greater on scalps and rakes than on tracks. The general reductions in cover in later years arose from a reduction in herb cover, especially in grass species.

Discussion

Following stumping at the Gates Creek site, generally poor soil conditions, i.e., soils significantly denser and less penetrable than undisturbed soil, resulted in significantly reduced height growth of Douglas-fir after 5 years on all five disturbance categories. On a percentage basis, detrimental growth impacts were even greater after 8 years but the lower sample size following thinning resulted in fewer statistically significant differences. Poorest growth occurred on tracks in the stumped treatments; this was the result of dense soils and seasonal waterlogging. Generally poorer growth of trees on drastically disturbed soil is consistent with the majority of studies of this nature (Lousier 1990). Ponding of water was not recorded for the looser, more permeable soils at the Phoenix site. In the latter site, the disturbance caused by stumping was either significantly beneficial to the growth of Douglas-fir and, by the 8th year, western larch, or had no significant effect, depending on the disturbance category. Differences in parent material markedly affected the growth response of trees as indicated earlier for site preparation (Corns 1988) and for harvesting (Smith and Wass 1979, 1980).

Differences in the response of tree species to disturbance were also evident. After 5 years,

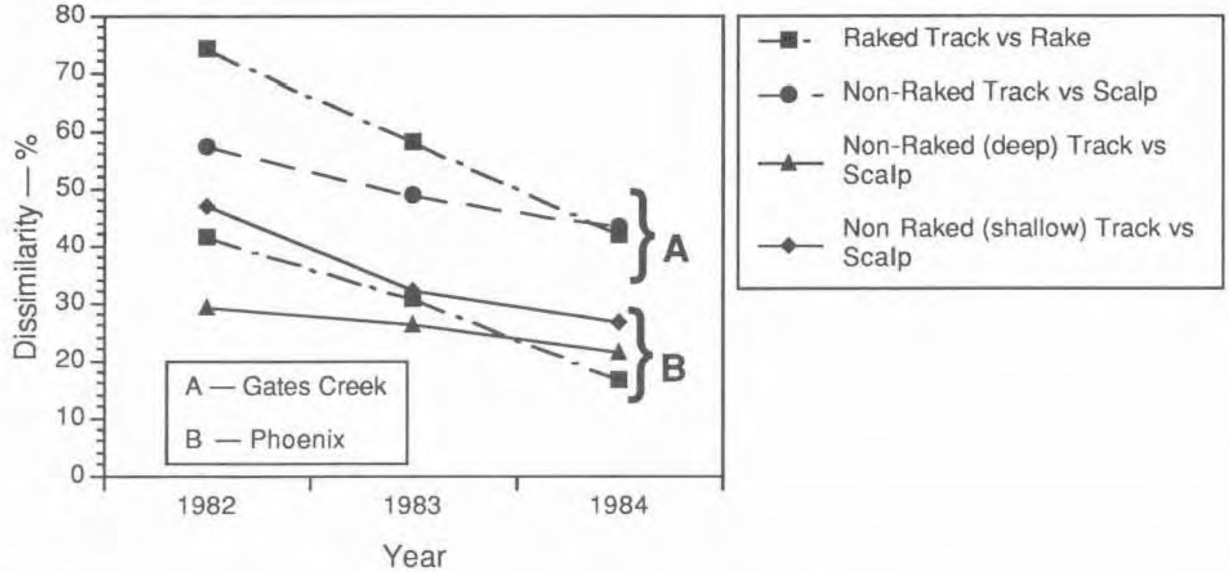

Figure 19. Dissimilarity percentages for vegetation composition and cover for paired comparisons of within treatment disturbance categories at the Gates Creek and Phoenix sites for 3 years.

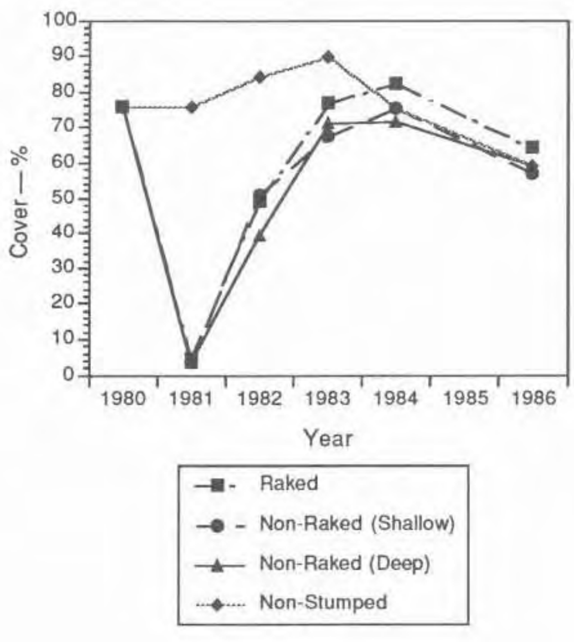

Figure 20. Total percentage cover of vegetation before and for 5 years after harvesting and stumping for four treatment types at the Phoenix site.

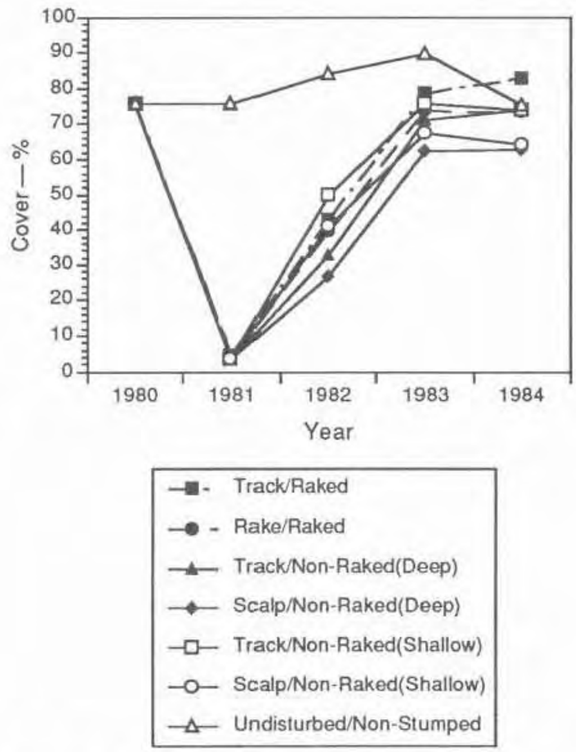

Figure 21. Total percentage cover of vegetation before and for 3 years after harvesting and stumping for the undisturbed soil and six categories of disturbance at the Phoenix site.

lodgepole pine at Gates Creek was less adversely affected by soil disturbance than Douglas-fir; they grew as well in terms of height on disturbed as on undisturbed soil or sometimes significantly better. This confirmed the commonly-held view of lodgepole pine as a rapidly growing seral species able to thrive on a variety of soils with relatively modest demands on the site (Krajina 1969; Weetman 1988). However, the eighth-year data show a downward trend in the growth of lodgepole pine on disturbed soil compared with undisturbed soil and the absence of any significant advantage of growing on disturbed soil. The initial advantages for lodgepole pine growing on disturbed soil were obviously not operative in the later years. One likely reason for this was the natural increase in levels of plant cover on the disturbed areas and the beginning of manual vegetative control after the fifth year with the resulting tendency toward equalization of vegetative competition on disturbed and undisturbed soil. The result of this equalization would tend to make tree growth rates more reflective of soil conditions. The most contrasting disturbance classes were tracks versus rakes or scalps. For Douglas-fir at the Gates Creek site, tracks were a decidedly poorer substrate for growth up to 8 years when compared with rakes or scalps. At 5 years, even lodgepole pine grew significantly better on rakes than on adjacent tracks. However, for Douglas-fir at the Phoenix site, the poorer performance on tracks was only recorded at 5 years in the non-raked (deep) treatment type, again demonstrating the greater resistance to degradation displayed by the soil at the Phoenix site.

All categories of soil disturbance enhanced tree survival rates at Phoenix, whereas survival at the Gates Creek site was not improved on the compact tracks. This again emphasizes the more sensitive nature of the Gates Creek site.

Can these differences between the two sites and between disturbance classes at each site be explained by the pedologic data? Based on the extent of mineral soil exposure alone, no important differences between the sites were found. However, an examination of the depth of disturbance revealed a much higher percentage of very deep disturbance on the Gates Creek site than at the Phoenix site. This deeper disturbance at Gates Creek was associated with greater impacts on individual soil characteristics. A relationship between depth of displacement and the magnitude of changes in soil characteristics would be expected, given the increasing soil density and resistance to penetration and the decreasing organic matter content with increasing depth in undisturbed soils at both sites. Similar trends are common in soils in other parts of southern interior British Columbia (Smith and Wass 1985). The importance of a natural increase in bulk density with soil depth was stressed earlier by Dyrness (1965) for soils in the Oregon Cascades. The greater increase in bulk density over natural levels found in tracks at the Gates Creek site compared with the Phoenix site was probably the result of deeper rutting but, as indicated by the comparison of bulk densities in tracks and in undisturbed soil at equivalent depths, also the greater compactibility of the soils at the Gates Creek site.

The generally higher volumetric soil moisture content in spring and mid-summer on tracks versus rakes and scalps points to a greater reception and retention of moisture in the more compact tracks. This should prove to be an advantage for early survival of planted trees, but this was not indicated in this study. In fact, excess moisture in some tracks at Gates Creek probably was responsible for low survival of Douglas-fir and was definitely related to poorer growth of both Douglas-fir and lodgepole pine. Other than the poor survival of Douglas-fir on tracks at Gates Creek, survival of planted stock at both sites was generally favored by reduced vegetative competition resulting from the mechanical disturbance.

Whereas physical properties of soils were significantly affected by the stumping operations, changes in chemical properties were not so clearly evident. Lowered contents of N and organic C in mineral soil after soil displacement were not realized except partly at Gates Creek. In the non-raked treatment at Phoenix, levels of N and C were, in fact, significantly higher in disturbed soil in several comparisons. High levels for N and organic C in disturbed soil likely comes from incorporation of woody material and humus into the mineral soil during stumping and windrowing, a supposition suported by the higher C/N ratios determined for disturbed soil.

Height was initially indicated to be the most sensitive measure of adverse effects of disturbance on tree growth, whereas diameter and volume best reflected beneficial effects of disturbance. This finding seems to be at odds with results of Froehlich *et al.* (1986) in which the volume of ponderosa pine (*Pinus ponderosa* Laws.) saplings was reduced more than height with increasing soil density. However, comparison of volume growth between tracks and rakes or between tracks and scalps in our study shows lower volumes on the more compact tracks in 8 of 10 possible comparisons after 5 years and in 9 of 10 possible comparisons after 8 years.

The differential response of height and volume to disturbance is likely a consequence of the lower vegetative competition in disturbed situations and the production of stockier trees than in the undisturbed situation. Chan and Walstad (1987) found that basal diameter of Douglas-fir was reduced most with increasing vegetative competition. In trials with white spruce (*Picea glauca* (Moench) Voss), MacKinnon and McMinn (1988) reported tall, thin seedlings associated with high vegetative competition and short, stocky seedlings associated with low vegetative competition. By the eighth-year, heights, diameters and volumes of trees growing on disturbed spots in our study were corresponding more closely to each other in their relationships to growth on undisturbed soil. Greater diameters and volumes reported for trees planted on stumped than on non-stumped sites in British Columbia (Morrison *et al.* 1988) and in Washington (Thies and Nelson 1988) were associated by those authors with reduced vegetative competition in the stumped sites.

Lepage (1984) showed that Douglas-fir at the Gates Creek site sampled 2 years after planting was deficient in N and that lodgepole pine had adequate supplies. Levels of N in foliage in both species apparently decreased during the period from 2 to 5 years by an average of 15% for Douglas-fir and 23% for lodgepole pine. The result of this was that at 5 years lodgepole pine was also considered slightly to severely deficient in N. The nutrients Ca, K, and Mg in foliage generally increased during the period from 2 to 5 years after planting and were not considered deficient for either species.

At Phoenix, N contents of foliage of both Douglas-fir and western larch growing on the undisturbed soil were significantly higher than on disturbed soil: this was opposite to what was indicated for growth. In fact, no deficiency occurred in N or for any other tested elements for Douglas-fir growing on undisturbed soil. Such a lack of correlation between foliage nutrient content and tree size suggests the possibility of nutrient dilution and the presence of confounding effects such as moisture stress (Stark 1988).

The greater sensitivity of Douglas-fir to disturbance than lodgepole pine at the Gates Creek site was supported by a greater range of plant moisture stress values, both pre-dawn and mid-day, for Douglas-fir than for lodgepole pine. Pre-dawn moisture stress values showed an inverse relationship to diameter growth of Douglas-fir. Any similar relationship was not apparent for lodgepole pine. Average mid-day stress values for Douglas-fir and lodgepole pine were above those reported to be associated with stomatal closure (Lopushinsky 1969), indicating that they were indeed stressed. The results of the plant moisture stress measurements for Douglas-fir, in which significant differences among disturbance types occurred at the Gates Creek site but not at the Phoenix site, further demonstrates the greater sensitivity of the Gates Creek site. However, both pre-dawn and mid-day moisture stress values for western larch at the Phoenix site were correlated with height, diameter and volume, indicating that the growth of this species was influenced by limits on water uptake.

At the Gates Creek site, slowest recovery of vegetation occurred in the raked treatment and there was somewhat slower development on tracks than rakes. After 4 years, vegetative cover on the raked area was about one-half that on the non-raked areas. In the non-raked areas cover was considerably higher on scalps than tracks. In contrast, compacted tracks at the Phoenix site supported higher vegetative cover than the adjacent looser scalps and rakes. In terms of productivity of vegetation, the soil at Gates Creek has been adversely affected by exposure of denser subsoils and compaction; at Phoenix, however, compaction has resulted in greater vegetative cover than decompaction. Differences in vegetative cover among treatments and among disturbance types within treatments were substantially greater at Gates Creek than at Phoenix.

Composition of plants differed more between adjacent disturbance types at Gates Creek than at Phoenix: dissimilarity percentages were 50-100% higher at the Gates Creek site. These results further suggest that stumping operations at Gates Creek produced microsites more unlike the original than these same operations did at Phoenix.

Since the stumping operation represented a mechanical site preparation operation, albeit a drastic form, the response of plant species other than the crop trees has interest for silviculturists. The stumping operations greatly reduced total vegetative cover, and thus probably competition to trees, for the first 3 years at Phoenix and 5 years at Gates Creek. At the Gates Creek site, raking after stumping and windrowing reduced vegetative cover considerably more than stumping and windrowing alone. This effect was not as evident at the Phoenix site. *Calamagrostis rubescens* and *Symphoricarpos albus* are known or suspected competitors (Haeussler and Coates 1986) and were discouraged by the stumping operations at the Gates Creek site. Potentially serious competitors encouraged by the drastic soil disturbance were *Rubus parviflorus*, *Epilobium angustifolium* and *Rosa gymnocarpa*. At Phoenix, a number of species were rendered insignificant by the stumping operation. However, of these only *Lonicera utahensis* would be considered a potentially serious competitor. Unlike the situation at Gates Creek, the known competitor *Calamagrostis rubescens* (Haeussler and Coates 1986) quickly recolonized the stumped areas. Species favored by the creation of exposed mineral soil at the Phoenix site were the sedges *Carex rossii* and *Carex concinoides*, neither of which are known to be serious competitors to trees.

Considerable attention has been focussed in British Columbia and other parts of North America on reducing losses in productivity resulting from forest soil degradation induced by forestry operations (Utzig and Walmsley 1988; Walmsley *et al.* 1988; Senyk and Smith 1989; British Columbia Ministry of Forests and Lands 1987). An important component of the recently issued harvesting guidelines for interior British Columbia is a site sensitivity rating (Lewis *et al.* 1989). Stricter guidelines apply to sites deemed highly sensitive to disturbance. When the sensitivity rating scheme was applied to the Gates Creek and Phoenix sites, the former was rated as moderate and the latter as low sensitivity. The greater sensitivity rating of the Gates Creek site resulted mainly from the presence of seepage (gleying) within 60 cm of the soil surface. The present harvesting guidelines do not differentiate between low and moderate sensitivity, i.e., the same maximum allowable disturbance would apply to each. These results suggest that the moderately sensitive Gates Creek site was considerably less robust than the low sensitivity site at Phoenix. Future revisions of the guidelines might include a lower soil disturbance limit for moderately sensitive sites than for sites of low sensitivity, particularly when the higher rating results from the presence of dense, gleyed, soil horizons near the surface.

Stumping operations on soils and terrain such as those present at the Gates Creek site can be improved by eliminating the windrowing phase and leaving the stumps in place, possibly upended in the holes left after stump extraction (Bloomberg and Reynolds 1988). This would greatly reduce soil displacement and compaction. Extracting stumps with an excavator rather than a bulldozer would reduce deep gouging (Smith and Wass 1989). Similar reductions in disturbance would be expected by using specialized stump pullers (H. Merler, British Columbia Ministry of Forests, Kamloops, personal commmunication). Using sufficiently wide, rear-mounted equipment for root raking would decompact the tracks of the prime mover and help maintain soil productivity. The brush blade used in the operations in this study loosened the surface 10 cm but was not effective in decompacting at greater depths. Particularly for sites with imperfect drainage, the production of microtopography conducive to ponding of water should be avoided by adjusting the orientation and reducing the extent of gouged and compacted concave surfaces. Results from both sites, but more so from Gates Creek, indicated that in the cool, moderately moist climates represented by the study sites, scalps and rakes should be favored over machine tracks as planting sites. For climatically or topographically drier sites, however, the advantages of loose soil may be outweighed by its low water-holding capacity.

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Table 1. Categories and depths of soil disturbance at the Gates Creek stumping site

Treatment	Disturbance category	Depth* SP	S	D	VD	Total
		% of area				
Uncut		0	0	0	0	0
Non-stumped	Track**	25	7	7	2	41
	Yarding	0	14	8	0	22
	Windrow	0	0	0	3	3
	Litter burned	0	2	0	0	2
	Undisturbed**	-	-	-	-	32
	Total	25	23	15	5	100
Raked	Rake**	0	0	39	0	39
	Track**	0	0	16	16	32
	Windrow	0	0	4	12	16
	Scalp	0	0	9	3	12
	Yarding	0	0	1	0	1
	Total	0	0	69	31	100
Non-raked	Scalp**	0	1	44	8	53
	Track**	0	0	13	20	33
	Windrow	0	3	1	10	14
	Total	0	4	58	38	100

* SP= Shallow press (no mineral soil exposed and generally <5 cm deep); S= Gouge or deposit <5 cm deep; D= Gouge or deposit 5-25 cm deep; VD= Gouge or deposit >25 cm deep.

** Soil disturbance categories on which trees were planted.

Table 2. Categories and depths of soil disturbance at the Phoenix stumping site

Treatment	Disturbance category	Depth* S	D	VD	Other	Total
		-----------------------------% of area				---------------------------------
Uncut		0	0	0	0	0
Non-Stumped	Undisturbed**	-	-	-	-	-
Raked	Rake**	0	35	0	0	35
	Track**	0	38	14	0	52
	Scalp	0	12	0	0	12
	Other	1	0	0	0	1
	Total	1	85	14	0	100
Non-raked (deep and shallow combined)	Track**	2	26	17	2	47
	Scalp**	4	39	7	0	50
	Pile	0	1	1	0	2
	Other	0	0	0	1	1
	Total	6	66	25	3	100

* S = Gouge or deposit < 5 cm deep; D = Gouge or deposit 5-25 cm deep; VD = Gouge or deposit > 25 cm deep.

** Soil disturbance categories on which trees were planted including tracks and scalps in both the deep and shallow non-raked treatments.

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

Treatment	Disturbance category	Samples	Depth: Total soil 0-10 cm	Total soil 10-20 cm	Fine soil 0-10 cm	Fine soil 10-20 cm
Non-stumped	Undisturbed	4	1.23 b*	1.51 b	0.87 b	1.06 b
	Track	6	1.61 a	1.70 ab	1.30 a	1.37 a
Raked	Rake**					
	Top	6	1.47 a	nm ***	1.15 a	nm
	Bottom	6	1.60 a	nm	1.30 a	nm
	Track	6	1.67 a	1.81 a	1.34 a	1.44 a
Non-raked	Scalp	12	1.12 b	1.18 c	0.82 b	0.88 b
	Track	6	1.72 a	1.68 ab	1.38 a	1.36 a

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

** Top = Top of furrow; Bottom = Bottom of furrow.

*** nm = not measured.

Table 4. Mean bulk densities (Mg/m^3) of total and fine soil fractions at Phoenix for seven disturbance categories plus the undisturbed mineral soil at two depths

			Depth			
	Disturbance		Total soil		Fine soil	
Treatment	category	Samples	0-10 cm	10-20 cm	0-10 cm	10-20 cm
Non-stumped	Undisturbed	4	0.82 ab*	1.05 b	0.65 abc	0.76 a
Raked	Rake**					
	Top	6	0.78 b	nm ***	0.57 bc	nm
	Bottom	6	0.88 ab	nm	0.64 abc	nm
	Track	6	0.99 ab	1.03 b	0.75 ab	0.76 a
Non-raked (shallow)	Scalp	6	0.71 b	0.59 c	0.49 c	0.44 b
	Track	6	0.76 b	1.16 b	0.55 bc	0.87 a
Non-raked (deep)	Scalp	6	0.67 b	0.65 c	0.46 c	0.45 b
	Track	6	1.09 a	1.46 a	0.79 a	0.96 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.
** Top = Top of furrow; Bottom = Bottom of furrow.
*** nm = Not measured.

Table 5. Mean resistance of soil (MPa) to penetration at Gates Creek for four disturbance categories in the raked treatment versus undisturbed mineral soil

			Depth (cm)		
Treatment	Disturbance category	No. of probes	0	7.5	15.0
Non-stumped	Undisturbed	17	0.38 c*	0.82 c	0.88 b
Raked	Rake**				
	Top	24	0.52 c	1.15 b	1.54 a
	Bottom	24	0.76 b	1.43 b	1.76 a
	Track				
	Lug	24	1.17 a	1.86 a	1.89 a
	Interlug	20	1.14 a	1.78 a	1.91 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.
** Top = Top of furrow; Bottom = Bottom of furrow.

Table 6. Mean resistance of soil (MPa) to penetration at Gates Creek for three disturbance categories in the non-raked treatment versus undisturbed mineral soil

Treatment	Disturbance category	No. of probes	Depth (cm) 0	7.5	15.0
Non-stumped	Undisturbed	17	0.38 b*	0.82 b	0.88 c
Non-raked	Scalp	24	0.28 b	0.75 b	1.23 b
	Track				
	Lug	24	0.86 a	1.52 a	1.90 a
	Interlug	24	0.79 a	1.68 a	1.96 a

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

Table 7. Mean resistance of soil (MPa) to penetration at Phoenix for four disturbance categories in the raked treatment versus undisturbed mineral soil

Treatment	Disturbance category	No. of probes	Depth (cm) 0	7.5	15.0
Non-stumped	Undisturbed	18	0.38 a*	0.49 b	0.47 b
Raked	Rake**				
	Top	24	0.11 c	0.16 c	0.46 b
	Bottom	24	0.20 b	0.57 b	1.07 a
	Track				
	Lug	24	0.16 b	0.64 b	1.30 a
	Interlug	24	0.18 b	0.92 a	1.40 a

* Means within columns followed by the same letter are not significantly different at the 0.05 level.
** Top = Top of furrow; Bottom = Bottom of furrow.

Table 8. Mean resistance of soil (MPa) to penetration at Phoenix for six disturbance categories in the non-raked treatment versus undisturbed mineral soil

Treatment	Disturbance category	No. of probes	Depth (cm) 0	7.5	15.0
Non-stumped	Undisturbed	18	0.38 a*	0.49 c	0.47 c
Non-raked (shallow)	Scalp	12	0.21 bc	0.30 c	0.48 c
	Track				
	Lug	24	0.14 c	0.61 c	1.16 b
	Interlug	24	0.13 c	0.75 bc	1.49 a
Non-raked (deep)	Scalp	12	0.17 b	0.30 c	0.47 c
	Track				
	Lug	24	0.25 b	1.02 ab	1.75 a
	Interlug	24	0.25 b	1.29 a	1.74 a

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

Table 9. Mean spring and mid-summer volumetric soil moisture contents (upper 20 cm) at Gates Creek for five disturbance categories plus the undisturbed soil

Treatment	Disturbance category	May 1987 Samples	May 1987 Moisture content (%)	August 1987 Samples	August 1987 Moisture content (%)
Non-stumped	Undisturbed	17	14.8 c*	18	3.4 c
	Track	19	20.0 b	18	3.9 c
Raked	Rake	18	19.3 b	19	5.3 bc
	Track	18	24.3 a	17	6.8 ab
Non-raked	Scalp	18	16.4 c	5	4.7 c
	Track	18	22.3 ab	3	7.3 a

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

Table 10. Mean spring and mid-summer volumetric soil moisture contents (upper 20 cm) at Phoenix for six disturbance categories plus the undisturbed soil

Treatment	Disturbance category	May 1987 Samples	May 1987 Moisture content (%)	August 1987 Samples	August 1987 Moisture content (%)
Non-stumped	Undisturbed	12	14.8 b*	12	5.6 ab
Raked	Rake	18	14.6 b	18	3.3 c
	Track	18	18.8 ab	18	5.1 ab
Non-raked (shallow)	Scalp	18	15.3 ab	18	3.9 bc
	Track	18	19.4 a	18	6.9 a
Non-raked (deep)	Scalp	17	15.4 ab	18	5.1 ab
	Track	19	19.7 a	18	6.6 a

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

Table 11. Mean gravimetric soil moisture contents at two depths on August 11-12, 1986, for five disturbance categories plus the undisturbed mineral soil at Gates Creek

Treatment	Disturbance category	Depth 0-10 cm Samples	Depth 0-10 cm Moisture content (%)	Depth 10-20 cm Samples	Depth 10-20 cm Moisture content (%)
Non-stumped	Undisturbed	12	9.5 a*	12	9.2 a
	Track	12	8.5 ab	12	9.2 a
Raked	Rake	12	6.1 c	11	10.8 a
	Track	12	6.3 c	12	9.0 a
Non-raked	Scalp	12	6.3 c	12	8.0 a
	Track	12	7.4 bc	12	10.1 a

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

Table 12. Mean gravimetric soil moisture contents at two depths on August 7-8, 1986, for six disturbance categories plus the undisturbed mineral soil at Phoenix

Treatment	Disturbance category	Depth 0-10 cm Samples	Depth 0-10 cm Moisture content (%)	Depth 10-20 cm Samples	Depth 10-20 cm Moisture content (%)
Non-stumped	Undisturbed	24	19.9 a*	24	18.4 ab
Raked	Rake	12	11.4 b	12	14.4 b
	Track	12	15.1 ab	12	14.5 b
Non-raked (shallow)	Scalp	12	15.4 ab	12	16.7 ab
	Track	13	15.0 ab	13	18.9 ab
Non-raked (deep)	Scalp	10	14.1 ab	11	19.4 ab
	Track	13	18.3 ab	13	21.4 a

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

Table 13. Mean heights, diameters and volumes of Douglas-fir after 5 and 8 years at Gates Creek for five disturbance categories and undisturbed soil

Treatment	Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
		----after 5 years----			
Non-stumped	Undisturbed	110	41.1 a*	9.7 b	12.1 a
	Track	99	38.3 b	9.5 b	11.8 a
Raked	Rake	164	36.9 bc	10.6 a	13.5 a
	Track	86	28.8 d	8.4 cd	7.0 b
Non-raked	Scalp	159	37.6 b	9.1 bc	10.3 a
	Track	112	34.4 c	7.8 d	6.9 b
		----after 8 years----			
Non-stumped	Undisturbed	37	75.2 a	22.5 a	122.6 a
	Track	37	70.0 ab	20.9 ab	115.6 ab
Raked	Rake	44	69.0 ab	21.8 a	115.8 ab
	Track	38	46.2 c	16.5 c	53.0 b
Non-raked	Scalp	43	65.3 ab	19.3 abc	85.4 ab
	Track	40	57.0 bc	17.4 bc	59.6 ab

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

Table 14. Mean heights, diameters and volumes of lodgepole pine after 5 and 8 years at Gates Creek for five disturbance categories and undisturbed soil

Treatment	Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
		after 5 years			
Non-stumped	Undisturbed	149	58.1 c*	12.8 d	31.9 c
	Track	150	60.0 bc	13.8 cd	36.8 bc
Raked	Rake	176	66.7 a	17.5 a	63.8 a
	Track	155	57.9 c	15.2 b	44.0 b
Non-raked	Scalp	173	61.9 bc	14.4 bc	42.6 bc
	Track	163	64.0 ab	14.2 bc	41.1 bc
		after 8 years			
Non-stumped	Undisturbed	38	133.3 a	34.6 ab	484.7 a
	Track	40	125.4 a	33.4 ab	421.0 a
Raked	Rake	44	135.3 a	37.2 a	537.4 a
	Track	41	118.7 a	32.5 ab	385.2 a
Non-raked	Scalp	43	129.0 a	37.3 a	561.6 a
	Track	43	121.1 a	32.0 b	383.8 a

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

Table 15. Effect of water ponding on growth of Douglas-fir and lodgepole pine growing in tracks at Gates Creek based on mean tree height, diameter and volume

Treatment	Distance from mapped ponded water	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
		-------------------Douglas-fir (5 years)	---------------------------		
Raked	< 1.0 m	16	24.6 b*	7.5 a	4.3 b
	> 1.0 m	70	29.8 a	8.6 a	7.6 a
Non-raked	< 1.0 m	19	30.5 b	5.9 b	3.3 b
	> 1.0 m	93	35.2 a	8.2 a	7.6 a
		-------------------Douglas-fir (8 years)	---------------------------		
All tracks	< 1.0 m	13	42.5 b	14.4 b	28.3 b
	> 1.0 m	102	59.5 a	18.7 a	81.4 a
		----------------Lodgepole pine (5 years)	-------------------------		
Raked	< 1.0 m	29	47.8 b	12.6 b	23.9 b
	> 1.0 m	126	60.3 a	15.8 a	48.6 a
Non-raked	< 1.0 m	21	60.8 a	13.2 a	33.9 a
	> 1.0 m	142	64.5 a	14.4 a	42.2 a
		----------------Lodgepole pine (8 years)	-------------------------		
All tracks	< 1.0 m	11	104.7 a	29.9 a	272.6 b
	> 1.0 m	113	123.3 a	32.9 a	408.3 a

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

Table 16. Mean heights, diameters and volumes of Douglas-fir after 5 and 8 years at Phoenix for six disturbance categories and undisturbed soil

Treatment	Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
		-----after 5 years-----			
Non-stumped	Undisturbed	79	39.2 c*	9.9 c	12.5 c
Raked	Rake	147	38.5 c	10.8 b	13.7 c
	Track	128	37.9 c	10.8 b	13.7 c
Non-raked (shallow)	Scalp	100	41.6 bc	11.4 b	17.2 bc
	Track	112	38.8 c	11.0 b	14.8 bc
Non-raked (deep)	Scalp	155	46.4 a	12.6 a	23.5 a
	Track	161	43.5 b	11.7 b	18.9 b
		-----after 8 years-----			
Non-stumped	Undisturbed	28	63.5 b	17.2 b	72.4 b
Raked	Rake	39	59.9 b	17.9 b	62.8 b
	Track	37	55.5 b	16.5 b	48.2 b
Non-raked (shallow)	Scalp	36	67.2 b	20.7 ab	124.0 ab
	Track	33	62.4 b	19.4 b	82.1 b
Non-raked (deep)	Scalp	45	86.3 a	24.3 a	168.9 a
	Track	45	83.5 a	24.3 a	172.3 a

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

Table 17. Mean heights, diameters and volumes of western larch after 5 and 8 years at Phoenix for six disturbance categories and undisturbed soil

Treatment	Disturbance category	No. of trees	Height (cm)	Diameter (mm)	Volume (cm^3)
		-------------after 5 years	-------------	-------------	-------------
Non-stumped	Undisturbed	56	87.7 ab*	15.9 bc	75.6 ab
Raked	Rake	142	70.7 c	15.6 c	51.7 bc
	Track	124	66.5 c	15.1 c	47.7 c
Non-raked (shallow)	Scalp	127	80.7 b	17.3 ab	89.1 a
	Track	116	79.1 b	17.5 ab	90.1 a
Non-raked (deep)	Scalp	168	90.3 a	18.2 a	97.9 a
	Track	154	81.8 b	16.8 abc	76.8 ab
		-------------after 8 years	-------------	-------------	-------------
Non-stumped	Undisturbed	21	181.1 b	32.1 c	703.1 bc
Raked	Rake	40	172.3 b	34.8 bc	666.7 bc
	Track	37	159.0 b	32.4 c	537.9 c
Non-raked (shallow)	Scalp	36	195.4 ab	40.2 ab	1124.3 ab
	Track	37	192.3 ab	37.9 abc	976.3 abc
Non-raked (deep)	Scalp	43	230.4 a	44.7 a	1367.2 a
	Track	41	192.8 ab	38.3 abc	976.1 abc

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

Table 18. Mean total dry weight of above-ground portions of Douglas-fir and lodgepole pine trees sampled at Gates Creek in 1982 and 1986

Treatment	Disturbance category	Douglas-fir No. of trees	Douglas-fir Weight (g)	Lodgepole pine No. of trees	Lodgepole pine Weight (g)
		-----September 1982-----			
Non-stumped	Undisturbed	16	1.4 a*	15	1.7 b
	Track	14	1.3 a	15	2.2 ab
Raked	Rake	21	1.4 a	21	2.9 a
	Track	22	1.5 a	21	2.7 a
Non-raked	Scalp	22	1.4 a	19	2.5 a
	Track	22	1.3 a	21	2.4 ab
		-----September 1986-----			
Non-stumped	Undisturbed	18	23.2 abc	17	43.2 c
	Track	18	20.6 abc	20	74.4 bc
Raked	Rake	18	31.6 ab	18	147.6 a
	Track	18	18.6 bc	18	93.6 b
Non-raked	Scalp	18	34.2 a	18	114.8 ab
	Track	18	14.1 c	20	88.3 b

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

Table 19. Mean total dry weight of above-ground portions of Douglas-fir and western larch trees sampled at Phoenix in 1982 and 1986

Treatment	Disturbance category	Douglas-fir No. of trees	Douglas-fir Weight (g)	Western larch No. of trees	Western larch Weight (g)
		September 1982			
Non-stumped	Undisturbed	17	2.3 a*	17	3.5 a
Raked	Rake	23	2.5 a	20	2.6 a
	Track	21	2.6 a	20	2.6 a
Non-raked (shallow)	Scalp	21	2.4 a	21	2.8 a
	Track	21	2.2 a	21	3.2 a
Non-raked (deep)	Scalp	20	2.6 a	20	2.7 a
	Track	21	2.4 a	23	2.6 a
		September 1986			
Non-stumped	Undisturbed	12	36.5 b	11	97.1 a
Raked	Rake	18	40.8 b	18	65.8 a
	Track	17	26.7 b	19	54.9 a
Non-raked (shallow)	Scalp	17	39.2 b	18	79.8 a
	Track	18	34.6 b	18	118.1 a
Non-raked (deep)	Scalp	18	73.3 a	18	83.4 a
	Track	19	36.6 b	18	99.7 a

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

Table 20. Mean content of nutrients in foliage of Douglas-fir and lodgepole pine at Gates Creek for three treatment types*

Nutrient	Douglas-fir			Lodgepole pine		
	Non-stumped	Raked	Non-raked	Non-stumped	Raked	Non-raked
	%					
N	1.16 a**	1.05 a	1.10 a	1.13 b	1.12 b	1.26 a
P	0.17 b	0.21 a	0.22 a	0.13 a	0.13 a	0.14 a
S	0.10 a	0.11 a	0.10 a	0.09 a	0.10 a	0.10 a
	ppm					
Ca	2730 a	2710 a	2880 a	2400 a	2586 a	2710 a
Mg	905 a	1300 a	1156 a	939 b	1149 a	1021 ab
Na	308 a	169 a	166 a	143 a	218 a	148 a
K	7582 a	8302 a	8772 a	6318 a	5942 a	6070 a
Fe	42 b	84 a	94 a	39 b	84 a	82 a
Mn	209 a	200 a	157 a	153 a	174 a	136 a

* Means are based on six bulked samples each consisting of foliage from six trees.

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

Table 21. Mean content of nutrients in foliage of Douglas-fir and western larch at the Phoenix site for four treatment types*

Nutrient		Treatment type			
		Non-stumped	Raked	Non-raked (deep)	Non-raked (shallow)
A.	Douglas-fir				
		%			
	N	1.67 a**	0.94 b	1.12 ab	1.35 ab
	P	0.25 a	0.15 a	0.22 a	0.15 a
	S	0.15 a	0.11 b	0.13 a	0.13 a
		ppm			
	Ca	3598 a	2378 a	3422 a	3326 a
	Mg	1537 a	842 a	1106 a	1418 a
	Na	87 a	148 a	106 a	88 a
	K	8343 a	7627 a	7322 a	9025 a
	Fe	65 a	102 a	40 a	50 a
	Mn	550 a	194 b	191 b	204 b
B.	Western larch				
		%			
	N	2.11 a	1.33 b	1.47 b	1.46 b
	P	0.40 a	0.38 a	0.33 a	0.35 a
	S	0.16 a	0.15 a	0.18 a	0.17 a
		ppm			
	Ca	2987 a	2758 a	2578 a	2498 a
	Mg	1075 a	916 a	874 a	877 a
	Na	48 b	171 a	110 ab	68 b
	K	9978 a	7079 b	7189 b	7540 b
	Fe	59 a	76 a	57 a	68 a
	Mn	702 a	410 a	268 a	435 a

* Means for the non-stumped treatment are based on three bulked samples and the other treatments are based on six bulked samples each consisting of foliage from six trees.

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

Table 22. Mean pre-dawn and mid-day moisture stress values (MPa) for Douglas-fir and lodgepole pine on August 11-13, 1986, at the Gates Creek site on five disturbance categories and on undisturbed soil*

Treatment	Disturbance category	No. of trees	Douglas-fir Pre-dawn	Douglas-fir Mid-day	Lodgepole pine Pre-dawn	Lodgepole pine Mid-day
Non-stumped	Undisturbed	6	0.68 bc**	2.03 b	0.64 a	1.68 a
	Track	6	0.56 c	2.09 b	0.58 a	1.61 a
Raked	Rake	6	0.83 abc	2.08 b	0.61 a	1.51 a
	Track	6	1.08 a	2.33 ab	0.73 a	1.51 a
Non-raked	Scalp	6	1.12 a	2.48 a	0.68 a	1.73 a
	Track	6	0.97 ab	2.17 b	0.57 a	1.61 a

* Weather during the period varied from partly cloudy to clear. Temperatures ranged from a minimum of 7°C to a maximum of 37°C.

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

Table 23. Mean pre-dawn and mid-day moisture stress values (MPa) for Douglas-fir and western larch as measured on August 6-9, 1986, at the Phoenix site for six disturbance categories and on undisturbed soil*

Treatment	Disturbance category	No. of trees	Douglas-fir Pre-dawn	Douglas-fir Mid-day	Western larch Pre-dawn	Western larch Mid-day
Non-stumped	Undisturbed	12	0.73 a**	1.80 a	0.74 a	2.16 a
Raked	Rake	6	0.78 a	2.15 a	0.72 a	2.43 a
	Track	6	0.81 a	2.09 a	0.82 a	2.41 a
Non-raked (shallow)	Scalp	6	0.91 a	2.11 a	0.92 a	2.41 a
	Track	6	0.82 a	2.17 a	0.97 a	2.28 a
Non-raked (deep)	Scalp	6	0.68 a***	1.99 a***	0.68 a	2.28 a
	Track	6	0.66 a****	1.90 a****	0.67 a	2.24 a

* Weather during the period was clear. Temperature ranged from a minimum of 1°C to a maximum of 33°C.

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

*** Five trees sampled.

**** Seven trees sampled.

Table 24. Average frequency (%) and cover (%) of plants (1982-84) at the Gates Creek site present in more than 40% of sampled plots arranged in order of increasing level of disturbance

					Stumped							
	Non-stumped				Non-Raked				Raked			
	Undisturbed		Track		Scalp		Track		Rake		Track	
Species	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover
Symphoricarpos albus	86	24	50	5	-	-	-	-	-	-	-	-
Calamagrostis rubescens	76	18	72	20	-	-	-	-	-	-	-	-
Thalictrum occidentale	64	6	47	7	-	-	-	-	-	-	-	-
Fragaria vesca	60	8	72	16	-	-	-	-	-	-	-	-
Fragaria virginiana	50	4	64	14	-	-	-	-	-	-	-	-
Paxistima myrsinites	88	4	64	2	54	1	-	-	68	1	-	-
Spiraea betulifolia	83	8	67	3	72	7	51	6	82	7	52	2
Arnica cordifolia	62	3	44	4	89	10	63	2	64	4	46	1
Rosa gymnocarpa	-	-	-	-	57	8	-	-	-	-	-	-
Rubus parviflorus	-	-	-	-	67	12	40	8	-	-	-	-
Carex rossii	-	-	-	-	-	-	40	2	-	-	-	-
Taraxacum sp	-	-	-	-	-	-	44	1	-	-	-	-
Epilobium minutum	-	-	-	-	63	5	68	1	94	2	-	-
Epilobium angustifolium	-	-	-	-	-	-	-	-	48	4	-	-
Trifolium repens	-	-	-	-	-	-	-	-	-	-	57	3

Table 25. Average frequency (%) and cover (%) of plants (1982-84) at the Phoenix site present in more than 40% of sampled plots arranged in order of increasing level of disturbance

	Non-stumped		Stumped											
			Non-raked								Raked			
	Undisturbed		Shallow Scalp		Deep Scalp		Shallow Track		Deep Track		Rake		Track	
	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover	Frequency	Cover
Lonicera utahensis	85	10	-	-	-	-	-	-	-	-	-	-	-	-
Linnaea borealis	68	7	-	-	-	-	-	-	-	-	-	-	-	-
Arctostaphylos uva-ursi	41	5	-	-	-	-	-	-	-	-	-	-	-	-
Antennaria racemosa	85	3	-	-	-	-	-	-	-	-	-	-	-	-
Lupinus sericeus	54	2	-	-	-	-	-	-	-	-	-	-	-	-
Hieracium cynoglossoides	44	1	-	-	-	-	-	-	-	-	-	-	-	-
Gentianella amarella	67	1	-	-	-	-	-	-	-	-	-	-	-	-
Achillea millefolium	43	1	-	-	-	-	-	-	-	-	-	-	-	-
Paxistima myrsinites	94	8	-	-	-	-	48	1	-	-	66	1	-	-
Thalictrum occidentale	67	2	-	-	-	-	-	-	-	-	42	1	-	-
Epilobium angustifolium	41	1	-	-	-	-	-	-	-	-	43	1	-	-
Festuca rubra	44	1	-	-	-	-	42	3	-	-	-	-	50	2
Calamagrostis rubescens	96	33	72	14	56	9	50	8	68	11	89	16	78	10
Fragaria virginiana	74	12	76	13	78	7	88	14	76	6	86	19	94	26
Fragaria vesca	54	3	54	4	59	4	52	3	65	6	72	6	72	7
Carex rossii	-	-	56	4	67	4	63	3	41	2	56	3	76	5
Carex concinoides	-	-	48	4	50	5	47	4	41	5	-	-	41	1
Rumex acetosella	-	-	44	4	-	-	52	3	-	-	-	-	-	-
Bromus vulgaris	-	-	-	-	-	-	-	-	41	4	-	-	-	-
Galium triflorum	-	-	-	-	-	-	-	-	-	-	-	-	46	4

Appendix

Plant species cited in text

Achillea millefolium Linnaeus	Common yarrow
Antennaria racemosa W.J. Hooker	Racemose pussytoes
Arctostaphylos uva-ursi (Linnaeus) K.P.J. Sprengel	Kinnikinnick
Arnica cordifolia W.J. Hooker	Heart-leaved arnica
Bromus vulgaris (W.J. Hooker) Shear	Columbia bromegrass
Calamagrostis rubescens Buckley	Pine grass
Carex concinoides Mackenzie	Northwestern sedge
Carex rossii F. Boott in W.J. Hooker	Ross' sedge
Chimaphila umbellata Linnaeus	Common western pipsissewa
Disporum hookeri (Torrey) Nicholson	Hooker's fairybells
Epilobium angustifolium Linnaeus	Fireweed
Epilobium minutum Lindley ex W.J. Hooker	Small-flowered willowherb
Festuca rubra Linnaeus	Red fescue
Fragaria vesca Linnaeus	Wood strawberry
Fragaria virginiana Duchesne	Wild strawberry
Galium triflorum A. Michaux	Sweet-scented bedstraw
Gentianella amarella Borner	Northern gentian
Hieracium cynoglossoides Arvet-Touvet	Hound's tongue hawkweed
Linnaea borealis Linnaeus	Northern twinflower
Lonicera utahensis S. Watson	Utah honeysuckle
Lupinus sericeus Pursh	Silky lupine
Paxistima myrsinites (Pursh) Rafinesque	Oregon boxwood
Rosa gymnocarpa Nuttal in Torrey and Gray	Baldhip rose
Rubus parviflorus Nuttall	Western thimbleberry
Rumex acetosella Linnaeus	Sheep sorrel
Spiraea betulifolia Pallas	Birch-leaved spiraea
Symphoricarpos albus Linnaeus	Common snowberry
Taraxacum Wiggers	Dandelion
Thalictrum occidentale A. Gray	Western meadow-rue
Trifolium repens Linnaeus	White clover