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Impacts of blading and burning site preparation on soil properties and site productivity in the sub-boreal spruce zone of central British Columbia

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Information Report BC-X-377
Pacific Forestry Centre, Victoria, British Columbia

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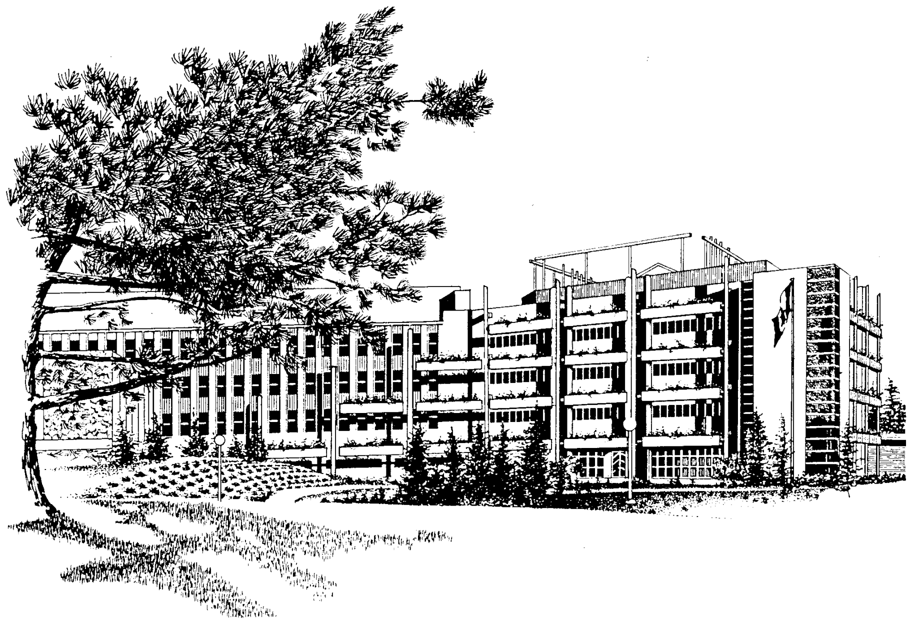

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Information Report BC-X-377

1998

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Phone (250) 363-0600

Printed in Canada

Canadian Cataloguing in Publication Data

Main entry under title:

Impacts of blading and burning site preparation on soil properties and site productivity in the sub-boreal spruce zone of central British Columbia

(Information report, ISSN 0830-0453; BC-X-377)
Includes an abstract in French.
Includes bibliographical references.
ISBN 0-662-26660-9
Cat. No. Fo46-17/377E

1. Forest soils -- British Columbia.
2. Forest site quality -- British Columbia.
3. Spruce -- British Columbia -- Growth.
I. Bulmer, Charles Ernest, 1954-
II. Pacific Forestry Centre
III. Title.
IV. Series: Information report (Pacific Forestry Centre); BC-X-377.

SD390.3B74156 1998 631.4'6'09711 C98-980092-X

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Abstract

We investigated soil factors and tree growth on sites that were clearcut during the 1970s and early 1980s and were subsequently site prepared with either blade scarification (blading) or prescribed fire (burning). Tree growth rates, evaluated as the mean internode length for the five years above breast height, were slightly higher for sites treated with blading than for those treated by burning. Differences in the concentrations and contents of soil C, N, P, K, Ca, Mg, and micronutrient cations between blading and burning treatments were generally not statistically significant. Contents of soil C, N, P, K, Ca, Mg and micronutrient cations for bladed sites were lower than for sites where no site preparation had occurred. Soil bulk density for all treatments was generally below the threshold where impaired tree growth is expected. Trees growing on bladed areas had higher concentrations of foliar N and P than trees growing in areas treated with burning. Foliar N levels were indicative of N deficiency for trees from both blading and burning treatments. The sites we examined were older (15-20 years) than many areas that have been studied to evaluate the effects of site preparation in the central interior of British Columbia. Although productivity appeared satisfactory at the time of this study, continued monitoring of the areas is recommended because of large nutrient losses that have occurred as a result of site preparation.

Résumé

Nous avons étudié certains facteurs édaphiques et ainsi que la croissance des arbres dans des stations ayant fait l'objet d'une coupe à blanc durant les années 70 et au début des années 80, puis de travaux de préparation du terrain, soit par scarifiage à la lame, soit par brûlage dirigé. Pour évaluer le taux de croissance des arbres, nous avons mesuré la longueur moyenne des entre-nœuds situés au-dessus de la hauteur de poitrine, pendant les cinq années de l'étude. Ce taux s'est avéré légèrement plus élevé dans les stations scarifiées que dans les stations brûlées. En général, il n'y avait pas de différences significatives entre les stations scarifiées et les stations brûlées quant à la concentration et à la quantité présente de C, de N, de P, de K, de Ca, de Mg et d'oligo-éléments cationiques dans le sol. Par contre, la concentration de ces éléments dans le sol était légèrement inférieure dans les stations scarifiées que dans celles qui n'avaient subi aucune préparation du terrain. Pour tous les traitements, la densité apparente du sol est généralement demeurée en bas du seuil au-delà duquel surviennent normalement les problèmes de croissance. Les arbres poussant dans les stations scarifiées présentaient des concentrations foliaires de N et de P plus élevées que ceux poussant dans les stations brûlées. Les concentrations de N observées étaient indicatrices d'une carence en N, autant dans les stations scarifiées que dans les stations brûlées. Les peuplements étudiés étaient plus vieux (15 à 20 ans) que de nombreux peuplements ayant déjà servi à des études sur les effets de la préparation du terrain dans la région intérieure centrale de la Colombie-Britannique. La productivité semblait satisfaisante au moment de la présente étude, mais nous recommandons une surveillance continue de ces secteurs, étant donné les pertes importantes d'éléments nutritifs survenues à la suite de la préparation du terrain.

Acknowledgements

Funding for this project was provided by the McGregor Model Forest Association. Field work was carried out by Dawn Pasacreta, Paul Savinkoff, and Frances Swan. Soil and foliar analyses were conducted by staff at the Pacific Forestry Centre under the supervision of Ann van Niekerk, and by SoilCon Laboratories in Richmond, British Columbia. We thank Doug Maynard, John Senyk, and Ed Wass of the Pacific Forestry Centre for their thoughtful reviews of the manuscript.

1. Introduction

In central British Columbia, mechanical site preparation and prescribed fire have been used extensively to aid stand establishment. The major objectives of site preparation are to reduce the fire hazard, improve access for tree planters, create favourable microsites for tree seed or seedlings, and control competing vegetation (Otchere-Boateng and Herring 1990; Brockley et al. 1992). Although benefits are often observed early in stand establishment, concern has been expressed about the long-term productivity of areas that have been site prepared (British Columbia Ministry of Forests 1996; Brockley et al. 1992; Orlander et al. 1990).

Concern about site preparation may relate to unfavourable physical conditions resulting from machine traffic or to losses of nutrients. Degraded soil physical conditions are an avoidable side effect of mechanical site preparation, but nutrient losses are an unavoidable consequence of mechanical site preparation and prescribed fire treatments aimed at reducing the amount of logging slash on areas to be replanted. While some results have shown that mechanical site preparation and prescribed fire can lead to nutrient deficiencies and reduced plantation performance (Herring and McMinn 1980; Ballard 1985), short-term results often show that tree growth is either unaffected or improved where organic matter levels are reduced by scarification (e.g., Munson et al. 1993). Orlander et al. (1996) summarized several studies from Scandinavia showing no negative long-term effect of site preparation, despite some nutrient losses.

The short-term and long-term effects of mechanical site preparation on productivity depend on factors such as initial site conditions, tree species and stock types, types of practices, and types of soil disturbance created. To ensure that mechanical site preparation and other forestry practices do not degrade the inherent productive potential of forest lands, forest managers and policy makers in British Columbia and elsewhere have developed guidelines for appropriate application of these practices, and for evaluating their role in sustainable forest management (British Columbia Ministry of Forests 1996; Canadian Council of Forest Ministers 1996). Understanding the effect of mechanical site preparation on soil characteristics, and the subsequent effects on productivity, is necessary to ensure that guidelines are realistic and that efforts to monitor the effects of forest practices focus on those characteristics that serve as reliable indicators of productivity.

This report describes the results of a project that examined harvested and site-prepared areas in the sub-boreal spruce biogeoclimatic zone of central British Columbia, 15 to 20 years after treatment. Our objective was to evaluate the effect of blade scarification (blading) and prescribed fire (burning) on soil properties and tree growth for two soil types (glaciofluvial and lacustrine). Soil properties were also compared to control areas that had not been site prepared. A secondary objective was to evaluate the use of soil and tree measurements as indicators of sustainable forestry in central British Columbia.

2. Materials and methods

2.1 Study area

The study was carried out in the McGregor Model Forest, located 30 km northeast of Prince George (54° N, 122° W), in the montane and subalpine forest regions of central British Columbia. The study area is in the wet cool (SBSwk1) variant of the sub-boreal spruce (SBS) biogeoclimatic zone (DeLong, C., British Columbia Ministry of Forests, Prince George. A field guide for site identification and interpretation for the southeast portion of the Prince George Forest Region. Land Management Handbook, in preparation). The study area lies within the McGregor Plateau (Holland 1976), an area with gentle topography. Surficial materials on the McGregor Plateau include medium to coarse-textured morainal blankets (greater than 1 m thick) and veneers (less than 1 m thick) overlying bedrock, colluvial materials at higher elevation, along with lacustrine and fluvial materials at lower elevation. The areas selected for this study were restricted to lacustrine and glaciofluvial parent materials.

The dominant soil processes occurring in this landscape are podzolization and lessivage (Dawson 1989). Luvisolic soils develop in upland sites on lacustrine and medium-textured glacial till parent materials. On the coarse-textured morainal and glaciofluvial parent materials, Podzolic soils form on well-drained sites. These soil orders reflect generally moist conditions west of the Rocky Mountains, with excess soil moisture contributing to transport of clay and release of sesquioxides within soil profiles.

2.2. Sampling design

Three plots (cutblocks) with each of the site preparation treatments (blading and burning) were established on coarse-textured glaciofluvial parent materials. On fine-textured, lacustrine parent materials, two plots were established in burned areas, and one plot was established in a bladed area. Three plots with no site preparation on glaciofluvial parent materials were located and evaluated for soil properties, but no conifer productivity measurements were obtained because there were insufficient surviving trees. Slope on the plots ranged from 0 to 23%, humus forms were Mors, and the effective rooting depth ranged from 13 to 32 cm.

The treatments can be considered as a sequence with extensive removal of organic matter (blade site preparation), moderate removal (burn site preparation), and no removal (no site preparation). Measurements were made in places where soil physical properties had been relatively unaffected by machine traffic in order to evaluate the effect of site preparation. Compacted areas, wheel ruts, skid trails, roads or landings were not sampled.

2.3 Plot and subplot selection

Plots were selected from 15- to 20-year-old cutblocks based on records obtained from Northwood Pulp and Timber. Before sampling, candidate plots were visited to ensure that: (1) access was possible, (2) predominant site series were circum-mesic (01, 04, 05) within the SBSwk1 and SBSvk1 biogeoclimatic subzone variants, (3) site conditions generally reflected those expected based on the site preparation treatment indicated on the forest cover map, and

(4) enough trees of suitable size were available for site index determination using the growth intercept method (British Columbia Ministry of Forests 1995).

Within each plot, forest productivity and soil properties were evaluated at subplots established at 25-m intervals along transect lines. Transect lines were established along a random bearing, and individual subplots were evaluated for their suitability for measurement of soil conditions and forest productivity based on site series, evidence of appropriate treatment impacts, and sufficient numbers of suitable trees experiencing relatively uniform soil conditions. Seven subplots were established in each plot except for one plot in which ten subplots were established. In each plot, one of the subplots was identified for location of a main soil pit. Transect and subplot locations were described relative to an identifiable tie point (such as a road junction, bridge, culvert, stream crossing, or pond) using a compass and hip chain. Field work was carried out during the summer of 1995.

2.4. Soil description, sampling, sample preparation, and analysis

Forest floor (L, F, and H) material was sampled by horizon at the seven subplots in each plot. Sampling was usually carried out at the subplot center on the transect line. However, on most bladed subplots, forest floor material was collected from under nearby conifer regeneration due to insufficient accumulation at sampling points. Percent coverage of the forest floor was also estimated in the field.

At six of the subplots, two soil pits were excavated, horizon depths were recorded, and mineral soil was collected by horizon to either the rooting depth or 30 cm, whichever was reached first. In all cases, two soil horizons and thus two samples fell within this depth. The two samples were identified as the upper and lower mineral soil samples from each sampling point, regardless of the identity of the horizon.

At the seventh site, a main soil pit was excavated to 1 m and sampled to the parent material. Samples from the two uppermost mineral soil horizons in the main pits were designated as upper and lower, as in the small pits. Major features such as colour, texture, coarse fragment content, presence of root restricting layers, and effective rooting depths were described according to Luttmerding et al. (1990), and according to the methods required to evaluate the site moisture and nutrient regime, as described in Klinka et al. (1994).

Forest floor bulk density was determined at the main pits by collecting from a 0.04-m^2 area. The sample was removed by inserting a shovel along the mineral-organic soil interface after cutting the edges of the sample with a knife. The depth of the forest floor was measured, and the oven-dried mass of each sample was determined. Mass of forest floor per unit area was also calculated. Bulk densities for the upper and lower mineral horizons were evaluated at each of the seven subplots using the core method (Culley 1993). Forest floor bulk density samples were dried at 50°C, and mineral soil bulk density samples were dried at 70°C. Preliminary work revealed that using these temperatures resulted in bulk density estimates that were usually within 1% of those obtained by drying at 105°C. Management history, vegetation characteristics, and descriptions of the main soil pits are provided in Tables 1 and 2. Examples of soil profiles are presented in Figure 1.

Figure 1. Soil profiles on (a) fluvial burned, (b) fluvial bladed, and (c) locustrine burned sites.

Samples were air dried in paper bags, passed through a 2-mm sieve and coarse fragment (gravel) content was determined. Mineral soil samples were analyzed at the Pacific Forestry Centre laboratory for C using a LECO CR12 Organic Carbon Determinator, total N using a LECO FP228 Organic Nitrogen Determinator, mineralizable N by anaerobic incubation (Bremner 1966), exchangeable K, Mg, and Ca with NH_4Cl (Kalra and Maynard 1991), DTPA extractable Fe, Mn, Zn, and Cu (Liang and Karamanos 1993). For forest floor samples, C was determined using a LECO CR12 Organic Carbon Determinator. Total N, P, K, Fe, Cu, Al, Mn and Zn in forest floors were determined on acid digests (Parkinson and Allen 1975) using a Technicon autoanalyzer II (Industrial method 334) for detection of N, and ICP spectroscopy for detection of P, K, Fe, Cu, Al, Mn and Zn. Forest floors were analyzed at the Pacific Forestry Centre laboratory. Bray phosphorus (Kalra and Maynard 1991) and soil pH in $CaCl_2$ (Kalra and Maynard 1991) were determined for mineral soils at SoilCon Laboratories (Richmond, British Columbia). Particle size on selected samples was determined using the hydrometer method (Sheldrick and Wang 1993) at Simon Fraser University.

2.5. Conifer productivity measurements, foliar sampling, and foliar analysis

At each subplot, 15 white spruce trees with at least five undamaged whorls of branches above breast height were randomly selected. For each tree, mean height at breast height age of five years was measured as the distance from the ground to the fifth whorl above breast height (British Columbia Ministry of Forests, 1995). An average internode length for those five whorls was also calculated. Diameter at breast height (DBH) and total tree height were also measured. The usefulness of total tree height as a measure of productivity was limited because many of the sample trees had been attacked by spruce weevils. Average internode length was determined only for undamaged portions of the stem, and therefore provides a more reliable estimate of site productivity. Foliar samples were collected from five to seven white spruce trees per subplot in late September 1995 according to methods described in Ballard and Carter (1985). Samples were oven-dried at 70℃, then shipped to Pacific Forestry Centre for determination of 100-needle weights and concentrations of N, P, K, Ca, Mg, Fe, Zn, Mn, Al and Cu (Parkinson and Allen 1975).

2.6. Data analysis

2.6.1. Determination of soil variables

2.6.1.1. Soil nutrient concentration and pH

Where more than one forest floor horizon could be sampled in a subplot (e.g., L and F horizons), the mean forest floor nutrient concentrations for the subplot were calculated, weighted by horizon thickness. Nutrient concentrations for mineral soils and forest floors, and spruce growth data from individual subplots, were averaged to obtain plot means, and plot means were averaged to obtain treatment means. Nutrient concentration and pH values for the upper and lower mineral soil samples from each subplot were averaged to obtain plot means of nutrient concentrations and pH values for each horizon.

2.6.1.2. Soil nutrient content

Nutrient contents (kg ha^{-1}) for the forest floor were determined for each subplot using the mean bulk density of three plots per treatment for burned and no site preparation treatments, while a single bulk density value was used in the calculations for the bladed treatment. Because the amount of forest floor present on the sites was highly variable, the percentage of the ground surface covered by forest floor was also considered in the determination of nutrient content. Forest floor covered 100 % of the surface of no site preparation plots. For burned plots, coverage varied from 27.5 to 100% (mean 67.5%). A value of 10% was used for bladed plots.

Nutrient content was determined for each upper and lower mineral soil horizon. Mean treatment bulk density was used to calculate nutrient contents. Nutrient contents for each horizon were then corrected for coarse fragment content using the mean of two coarse fragment content determinations for that horizon. Corrected nutrient contents were averaged to obtain plot means.

In addition to considering each of the three soil horizons separately, soil nutrient data were also evaluated on the basis of total soil volume in the rooting depth (forest floor and mineral soil combined), and the total volume of the mineral soil (mineral soil horizons combined). When soil horizons were combined, nutrient concentrations were averaged for horizons, weighted by horizon thickness. Soil nutrient contents were summed for horizons.

2.6.2. Analysis of variance

Analysis of variance (ANOVA, Steele and Torrie 1980) was used to determine treatment differences in glaciofluvial site forest floor and mineral soil properties, and foliar nutrient concentrations and contents with the aid of SPSS (SPSS Inc. 1994). The data were analysed as a completely random design with three site preparation treatments and three replicates of each treatment. We tested for the effect of site preparation using the following model:

$$Y_{ij} = u + S_i + e_{ij}$$

where S is site preparation treatment (i = 1,2,3: blading, burning, no site preparation) and e is random error within treatment. A significance level of p=0.05 was used in testing for significant differences.

ANOVA was not carried out for lacustrine soil properties, foliar nutrition, or tree growth due to incomplete experimental design. Homogeneity of variance was tested for each variable prior to the analysis of variance. Where variances were not homogeneous, the data were log-transformed and then tested again. Mean separation was done using Bonferroni's test.

Statistical analyses of growth data on bladed and burned glaciofluvial plots were carried out for mean internode length above breast height and mean height at breast height age of five years. These indices circumvent some of the confounding factors on the plots: namely, differences in tree age due to time of planting, and effects of spruce weevil attack on height development. Measures of current yield such as DBH, basal area, total height, and volume are not directly comparable under these conditions.

2.6.3. Simple linear regression analysis of soil, foliar, and growth properties

Simple linear regression analysis (SPSS Inc. 1994) was used to identify relationships between soil nutrient status and foliar nutrition, foliar nutrition and growth, and soil nutrient status and growth. Glaciofluvial and lacustrine plots were considered seperately. Data from subplots were used as observations for dependent and independent variables. Mean internode length above breast height was used as the growth variable in the regressions. Soil data were used for all horizons combined (nutrient content) or for mineral horizons combined (concentration and content).

3. Results and discussion

3.1. Soil properties

3.1.1. Horizon depths and bulk density

The type and average depth of soil horizons sampled in each treatment is shown in Figure 2. The identity of the forest floor and upper two mineral horizons are indicated as a proportion of all samples within those treatments and sampling depths. The forest floor was significantly thinner in the bladed treatment than in the other treatments 15 to 20 years following site preparation and 15 years after stand establishment (Table 3). Despite the variability in forest floor and mineral soil horizon thickness, total sampling depth was similar over all treatments, with means of 26.0, 26.3, and 25.1 cm for the bladed, burned, and no site preparation treatments, respectively. Mean bulk densities of forest floor and mineral soils (Table 3), were generally below the threshold range (1.2 to 1.4 g cm^{-3}) for impaired root growth (Lousier 1990).

Figure 2. Type and depth of soil horizons sampled, by treatment (fluvial sites).

3.1.2. Soil nutrient status

Significant differences in forest floor element concentration under the three treatments on glaciofluvial plots were observed only for Mn (Table 4). Manganese concentration was greater in the burned treatment than in the bladed treatment, and was intermediate in the no site preparation treatment. Forest floor C, N, P, K, macronutrient cation, and micronutrient cation contents were greater in the plots with no site preparation treatment than in the bladed or burned treatments, and there were no differences between the bladed and burned treatments. The differences in element content reflect the lack of forest floor coverage on the bladed plots compared to the plots with no site preparation. Burned plots had intermediate coverage of forest floor.

Treatment differences in mineral soils for glaciofluvial plots were limited to the C:N ratio in the upper mineral soil (Table 5). The C:N ratio was greatest on the bladed plots and lowest on the burned plots. There were no treatment differences in mineralizable N concentrations in mineral soils. Values of mineralizable N observed for bladed and burned plots were comparable to the medium nutrient regime for spruce sites based on mineralizable N proposed by Klinka et al. (1994). Soil pH in the upper and lower horizons did not differ among treatments.

For glaciofluvial soils, mean N concentration in combined upper and lower mineral soils was greatest in the no site preparation treatment and lowest in the bladed treatment (Table 6). Treatment differences were not observed for other nutrients. Nutrient concentrations in forest floors and mineral soil on lacustrine plots are shown in Tables 7 and 8 for comparison.

There were no significant treatment differences in mineral soil nutrient contents (Table 9). Carbon, N, K, macronutrient cation and micronutrient cation contents of the entire soil profile were all significantly different among the treatments and were greatest in the no site preparation treatment and lowest in the bladed treatment (Table 10). There were no differences in soil nutrient content among treatments in the total mineral soil (Table 11). Differences in forest floor nutrient content appear to be driving differences in nutrient content over the entire profile. Nutrient contents in forest floor and mineral soil on lacustrine plots are presented in Tables 7 and 12.

3.2. Foliar nutrient status

Foliar N, P, and Zn concentrations were significantly greater in the bladed treatment than in the burned treatment (Table 13). Foliar N concentrations under both treatments are indicative of N deficiencies, based on the diagnostic criteria of Ballard and Carter (1985), and would likely show a growth response to N additions (Swift and Brockley 1994). Foliar P and Zn concentrations are adequate under both treatments. Values of foliar Mg were consistently below critical values for blading and burning treatments. Foliar nutrient concentrations and contents from lacustrine plots are presented in Table 14 for comparison.

3.3. White spruce productivity on bladed and burned plots

For glaciofluvial plots, mean internode length above breast height was 7.5 cm or 21 % greater on the bladed plots than on the burned plots (Table 15). The mean height at breast height age 5 years was used to calculate the expected site index (SI 50) values of 22 m for bladed plots and 19.5 m for burned plots (British Columbia Ministry of Forests 1995). Means for lacustrine plots are also shown in Table 15 for comparison.

3.4. Relationships among soil nutrient status, foliar nutrient status and spruce productivity

Relationships between soil nutrient status (concentration and content) and foliar nutrient status for the same nutrient were weak and often negative (Tables 16 and 17). The negative relationships between mineralizable N and foliar nutrient status illustrates the complexity of the processes involved in nutrient acquisition, where factors such as the effect of soil temperature on root growth, and possible associations with mycorrhizal fungi can influence the ability of trees to obtain nutrients. The strength and sign of the relationships between foliar nutrient concentration and mean internode length varied depending on the nutrient and the soil type (Table 18). Relationships between soil nutrient status and growth on glaciofluvial sites were weak.

Soil nutrient content did not appear to be a better indicator of foliar nutrition or growth than nutrient concentration on either soil type. In mineral soils, relationships for mineralizable N were no better than those using soil total N concentration. A common feature of these relationships is that the bladed and burned subplots appear as identifiable clusters (Figures 3 and 4), indicating that trees growing on bladed sites tended to have higher concentrations of foliar N and P and somewhat higher growth rates than trees growing on lacustrine plots.

Figure 3. Foliar N concentration vs. mean internode length above breast height (fluvial sites) r^2=0.45 (p<0.0001)

Figure 4. Foliar P concentration vs. mean internode length above breast height (fluvial sites) r^2=0.35 (p<0.001)

4. Conclusion

Our results have shown that site preparation had dramatic effects on the contents of soil organic matter and nutrients, but not on nutrient concentrations. Soil carbon and nutrient contents were lower for the bladed areas than for areas with no site preparation at least 15 years after treatment. Areas treated with burning appeared to contain intermediate amounts of soil nutrients. However, decreased soil N content on bladed areas did not result in large differences in soil mineralizable N. Also, foliar nutrient concentrations and spruce growth rates, as evaluated by mean internode length for five years above breast height, were slightly higher for trees growing on bladed areas than for trees growing on burned areas.

Apparently, other environmental variables that were affected by the site preparation treatments, possibly including soil temperature and moisture status, along with the amount of competing vegetation, had a greater influence on soil nutrient availability, tree nutrient uptake and productivity than did the total carbon and nutrient contents. Cold soils limit tree root growth during parts of the growing season in many areas of the central interior, and treatments such as blading that remove forest floors and allow soils to warm more quickly in the spring can have positive effects on growth. Summer moisture deficits are very minor in the area of our study, so loss of soil organic matter that would also result from blading may have a only minor impact on water availability to trees in coarse-textured soils.

Despite previous evidence that soil mineralizable N can be used to predict soil nutrient regime and site index (Powers 1980; Klinka et al. 1994), there is a great deal of natural variation among stands, and relatively large differences in soil mineralizable N are associated with relatively small changes in site index. In our study, mineralizable N values did not cover the range of values where large differences in site index are expected. For our sites, foliar nutrient status was a better predictor of growth response than were soil nutrients, in agreement with Ballard and Carter (1985).

Although Orlander et al. (1990) suggested that harsh site preparation should be avoided on poor sites with thin humus layers, and on dry or coarse-textured soils, our results show that harsh site preparation (blading) had not resulted in reduced growth relative to burning after approximately 15 years. In northern Manitoba, Ball (1990) found that blading had negative effects on white spruce growth twenty years following treatment. Other studies have shown that long-term effects of site preparation on conifer productivity are variable. Lasting effects of site preparation vary with the properties of the site and the intensity of the treatment (Orlander et al. 1996; Smith 1996). It appears that on our sites, the nutrient losses that occurred on the bladed sites were not sufficient to cause a decrease in productivity after 15 years. This is especially interesting because coarse-textured soils such as these generally do not contain large reservoirs of nutrients or organic matter. Soil physical properties may have been mildly affected by these treatments, but did not appear to limit productivity on these coarse-textured soils which are not expected to be sensitive to degradation by machine traffic. It has been shown, however, that the impacts of site preparation treatments may intensify over the length of a rotation (Dyck and Skinner 1990; Morris and Miller 1994). Longer periods (possibly a minimum of 20 to 30 years) may be required to better evaluate the cumulative effects of nutrient removals on site productivity (Smith 1996).

One of the broader objectives of this work was to evaluate potential indicators of sustainable forest management in the sub-boreal spruce forests of central British Columbia. The weak and variable relationships we have observed between soil organic matter and nutrient status and spruce productivity for these sites, and the inverse relationships between soil nutrient content and foliar nutrient concentrations, illustrate the difficulties associated with using detailed measures of soil nutrient status as indicators of sustainable forest management.

Soil organic matter content has been proposed as a key indicator of soil function, partly because it is relatively easy to evaluate. Despite the obvious importance of soil organic matter for soil productivity, our results show that measures of forest productivity are not always well correlated with soil organic matter content. Therefore, evaluation of productivity and soil quality using soil organic matter need to be considered in the context of site temperature and moisture conditions, as well as a consideration of the many ways that soil organic matter affects soil quality, including the large differences between total organic matter content, and active fractions affecting nutrient status and trophic community activity (Fisher 1995). Similarly, differences likely exist between total organic matter content and fractions associated with stabilizing soil structure and porosity.

Even though height growth is one of the best indicators for evaluating long-term site productivity, reliable data from controlled experiments are difficult to obtain in north central British Columbia, and even in areas where longer-term records are available, interpretation of such growth data is not without problems. Burger (1996) observed that stand growth response to site preparation treatments are affected by many factors, the effects of which may be expressed at various times throughout the rotation, even over periods of 50 years and more. The response of tree height growth to site and soil variability, limiting environmental factors for tree growth, and the effect of resource allocation to non-crop organisms also play a role in determining tree growth rates in response to forest management. Therefore, even long-term experiments based on bioassays need to be interpreted with caution. Our results, showing that trees growing on areas that were treated with harsh site preparation (blading) were growing as well or better than trees from burned areas after approximately 15 years, may not necessarily provide reliable predictions of future tree growth.

Despite the difficulties associated with collecting and interpreting information on soil conditions, it is an essential part of efforts to evaluate progress towards sustainable forest management. Standardized field procedures for conducting soil conservation surveys and describing soil disturbance that have recently been developed as part of British Columbia's Forest Practices Code are a practical approach to evaluating sustainability at this time. For the immediate future, we suggest that information from soil conservation surveys that may be carried out as part of ongoing obligations under the Forest Practices Code be used to evaluate the soil resource of growing sites within the sub-boreal spruce zone. Expected site index, based on evaluations of soil moisture and aeration regimes as described by Wang et al. (Wang, G.G., Klinka, K. and Moss, I. Guide to estimating interior spruce site index from edaphic factors in the Sub-boreal Spruce Zone. Contract report to Northwood Pulp and Timber. March 1994), may help to provide targets for productivity as new inventory information becomes available.

Our results suggest that the growth rates of spruce on the bladed and burned sites were satisfactory at the time of this study, but we believe they should be re-evaluated in approximately 10 years. Further assessment of tree growth rates using a variation of the height intercept method, and foliar nutrient analysis would be an appropriate strategy for identifying subsequent changes in tree productivity on these and other sites in the area.

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Tables

Table 1. Management history, vegetation, and soil characteristics of study sites on glaciofluvial parent materials.

CP 14-19 (BLADE) harvested in summer 1972, 1979 / blade site prep 1973, 1979 / planted 1980. White spruce, bunchberry, fireweed, hawkseed, twisted stalk, Indian hellebore, fern.

Horizon	*Depth (cm)*	*Description*
L	1.5-1	leaf litter with plentiful fine roots
F	1-0	fermentation layer, plentiful fine roots
Ae	0-8	light gray (7.5YR 7/1m); sandy loam; no coarse frags; abundant fine, coarse roots; discontinuous horizon
Bf1	8-25	yellowish red (5YR 4/6m); loamy sand; no coarse frags; plentiful fine and coarse roots
Bf2	25-46	strong brown (7.5YR 4/4m); sandy loam; no coarse frags; few fine and coarse roots
C	46+	light olive brown (2.5Y 5/4m); sand; no coarse frags; no roots

CP 14-17 (BLADE) harvested in summer 1976 / blade site prep 1975, 1979 / planted 1980. White spruce.

Horizon	*Depth (cm)*	*Description*
L	1-0	leaf litter with plentiful fine roots
Ae	0-6	brown (10YR 4/3m); loamy sand; no coarse frags; plentiful fine and coarse roots; discontinuous horizon
Bf1	6-28	yellowish red (5YR 4/6m); loamy sand; no coarse frags; plentiful fine and coarse roots
Bf2	28-40	strong brown (7.5YR 4/4m); loamy sand; no coarse frags; few fine and coarse roots
C	40+	light olive brown (2.5Y 5/4m); sand; no coarse frags; no roots

CP 14-03 (BLADE) harvested in summer 1976 / blade site prep 1979 / natural regeneration 1981. White spruce.

Horizon	*Depth (cm)*	*Description*
Bf1	0-11	yellowish brown (10YR 5/8m); sandy loam; no coarse frags
Bf2	11-24	light olive brown (2.5Y 5/6m); silt loam; no coarse frags
BC	24-40	olive yellow (2.5YR 6/4m); sandy loam; no coarse frags
C	40+	olive brown (2.5Y 4/3m); loamy sand; no coarse frags

CP 6-28 (BURN) harvested in winter 1973 / burn site prep / planted 1974. White spruce.

Horizon	*Depth (cm)*	*Description*
L	3-2	leaf litter; few fine roots
Fm	2-0	fermentation layer with abundant fine roots
Ae	0-9.5	pinkish gray (7.5YR 7/2m); loamy sand; 10% coarse frags; abundant fine, coarse roots
Bf	9.5-22	yellowish brown (10YR 5/8m); sandy loam; 10% coarse frags; abundant fine, coarse roots
BC	22-31	brownish yellow (10YR 6/6m); loamy sand; 10% coarse frags; plentiful fine, coarse roots
C	31+	red (2.5YR 6/4m); loamy sand; 10% coarse frags; few fine and coarse roots

CP 6-22 (BURN) harvested in summer 1971 / burn site prep 1972 / planted 1974. White spruce (90%), fir 5%, and pine. alder, grass, epilobium angustifolium, cornus canadensis, vaccinium membranosum.

Horizon	*Depth (cm)*	*Description*
Ln	6-4	fresh leaf litter; abundant fine, plentiful coarse roots
Fz	4-0	zoogenous fermentation layer, abundant fine and coarse roots
Ae	0-5	gray (5YR 6/1m); sandy loam; 20% coarse frags; abundant fine and coarse roots
Bm	8-11	dark yellowish brown (10YR 4/6m); loam; 40 % coarse frags: plentiful fine and coarse roots
BC	11-25	brown (7.5YR 4/4m); sandy loam; 55% coarse frags; few fine and coarse roots
C	25+	light yellowish brown (10 YR 6/4m); sandy loam; 70 % coarse frags; no roots

Table 1 cont.

CP 6-30 (BURN) harvested in summer 1971/ burn site prep 1972 / planted 1974. White spruce, aspen and cottonwood. Two species of vaccinium, blueberry, hawkseed, fireweed, paintbrush and fern.

Horizon	*Depth (cm)*	*Description*
L	3.5-3	patchy litter layer
Fm	3-0	fermentation layer containing nearly 50 % dead wood
Ae	0-4	pinkish gray (5YR 6/2m); sandy loam; no coarse frags; few fine and coarse roots
Bf	4-23	yellowish red (5YR 5/8m); loamy sand; no coarse frags; abundant fine and coarse roots
BC	23-42	olive yellow (2.5Y 6/6m); loamy sand; 5 % coarse frags; plentiful fine roots
C	42+	light olive brown (2.5Y 5/4m); sandy loam; 5 % coarse frags; no roots

CP 6-29 (NO SITE PREP) harvested in winter 1971/ no site prep / planted and NSR 1981. Tree cover consists of white spruce.

Horizon	*Depth (cm)*	*Description*
L	8-6.5	leaf litter
F	6.5-0	fermentation layer
Ae	0-3	gray (10YR 5/1m); silt loam; 5% coarse frags
Bf1	3-17	yellowish brown (10YR 5/8m); silt loam; 5% coarse frags
Bf2	17-37	olive yellow (2.5Y 6/6m); silt loam; 5% coarse frags
BC	37-65	light olive brown (2.5Y 5/4m); sandy loam; 40% coarse frags
C	65+	light yellowish brown (2.5y 6/4m); 40% coarse frags

CP 14-19 (NO SITE PREP) harvested in summer 1972 / no site prep (missed areas) / planted 1980. Tree cover consists of white spruce.

Horizon	*Depth (cm)*	*Description*
L	1.5-1	leaf litter with plentiful fine roots
F	1-0	fermentation layer, plentiful fine roots
Ae	0-8	light gray (7.5YR 7/1m); silt loam; no coarse frags; abundant fine and coarse roots
Bf1	8-25	dark red (2.5YR 3/6m); sandy loam; no coarse frags; plentiful fine and coarse roots
Bf2	25-46	dark red (10YR 4/4m); sandy loam; no coarse frags; few fine and coarse roots
C	46+	olive brown (2.5Y 4/4m): silt loam; no coarse frags; no roots

CP 10-06 (NO SITE PREP) harvested in winter 1964 / no site prep/ natural regeneration 1981. Tree cover consists of scattered advanced growth white spruce.

Horizon	*Depth (cm)*	*Description*
LFH	8-	litter/fermentation layer
Ahe	0-15	brown (7.5YR 4/3m); loam; 10% coarse frags; plentiful and fine coarse roots
Bm	15-30	dark grayish brown (10YR 4/2m); loam; 20% coarse frags; no roots
C	30+	light olive brown (2.5Y 5/6m); loam; 60% coarse frags; no roots

Table 2. Management history, vegetation, and soil characteristics of study sites on lacustrine parent materials.

CP 14-04 (BLADE) harvested in summer 1977 / blade site prep 1979/ natural regen 1981. Tree cover consists of white spruce.

Horizon	*Depth (cm)*	*Description*
F	1-0	fermentation layer
Ahe	0-13	brown (7.5YR 5/3m); silt loam; 5% coarse frags; plentiful fine and coarse roots
Bt1	13-40	light olive brown (2.5Y 5/4m); silt loam; no coarse frags; few fine roots
Bt2	40-66	light olive brown (2.5Y 5/4m); silty clay loam; no coarse frags; no roots
C	66+	olive yellow (2.5Y 6/6m); silt loam; no coarse frags; no roots

CP 13-12 (BLADE) harvested in winter 1976 / blade site prep 1976/ planted 1977. Tree cover consists of white spruce.

Horizon	*Depth (cm)*	*Description*
LF	1-0	litter/fermentation layer
Ahe	0-9	brown (7.5YR 4/4m); clay; 20% coarse frags
Btg	9-30	yellowish brown (10YR 5/4m); silty clay; no coarse frags
C	30+	brown (10YR 5/3m); clay; no coarse frags

CP 5-28 (BURN) harvested in winter 1977 / burn site prep 1977 / planted 1978. Tree cover consists of white spruce. Herbaceous vegetation includes V. membranosum, ribes, cow parsnip.

Horizon	*Depth (cm)*	*Description*
L	6-3.5	leaf litter
F	3.5-0	fermentation layer
Ae	0-8	dark grayish brown (10YR 4/2m); silty clay loam; 5% coarse frags; plentiful fine and coarse roots
Bf	8-20	dark yellowish brown (10YR 3/6m); silty clay; no coarse frags; plentiful fine and coarse roots
Bt	20-80	very dark gray (7.5YR 3/1m); silty clay loam; no coarse frags
C	80+	silty clay; no coarse frags

Table 3. Selected soil properties under different site preparation treatments for glaciofluvial and lacustrine plots. Values are means of three replicate plots per treatment.

	TREATMENT		
	Blade	Burn	No site preparation
Glaciofluvial plots			
forest floor depth (cm)	1.07 (0.47) *b*	5.22 (0.39) *a*	5.96 (0.68) *a*
forest floor bulk density (kg m^{-3})	170[1]	120 (30)	210 (70)
upper mineral soil bulk density (kg m^{-3})	1200 (60)	1260 (30)	1030 (130)
lower mineral soil bulk density (kg m^{-3})	1210 (30) *a*	1210 (< 10) *a*	1030 (70) *b*
Lacustrine plots			
forest floor depth (cm)	1.75 (.75)	5.0	na
forest floor bulk density (kg m^{-3})[2]	na	na	na
upper mineral soil bulk density (kg m^{-3})	891 (82)	769	na
lower mineral soil bulk density (kg m^{-3})	1171 (98)	1370	na

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$=0.05.
[1] single observation
[2] insufficient forest floor was present, bulk density not determined. Values for glaciofluvial plots were used in subsequent calculations
na = not applicable

Table 4. Forest floor element concentrations and contents under blading, burning, and no site preparation treatments on glaciofluvial plots.[1]

	TREATMENT			
	Blade	Burn	No site preparation	*p* values for treatment differences
C (g kg^{-1})	466 (15.8)	449 (14.2)	406 (12.5)	0.055
N (g kg^{-1})	12.3 (0.7)	12.6 (0.8)	16.2 (2.1)	0.17
C:N	38.6 (2.5)	38.5 (3.5)	27.1 (4.0)	0.085
P(mg kg^{-1})	1179 (9.9)	1412 (199)	1395 (105)	0.42
Ca (g kg^{-1})	16.2 (1.6)	14.5 (1.3)	11.6 (0.7)	0.11
Mg (mg kg^{-1})	1157 (82.1)	1125 (142)	1527 (288)	0.32
K (mg kg^{-1})	2044 (133)	2082 (251)	2200 (55.6)	0.80
Fe (mg kg^{-1})	1330 (477)	1874 (254)	3185 (857)	0.15
Cu (mg kg^{-1})	<75	<75	<75	
Al (mg kg^{-1})	1580 (509)	2989 (431)	4927 (1356)	0.089
Mn (mg kg^{-1})	1666 (206) *b*	3273 (268) *a*	2506 (210) *ab*	0.008
Zn (mg kg^{-1})	149 (10.6)	158 (51.4)	119 (11.1)	0.67
C (kg ha^{-1})	802 (322) *b*	19186 (5492) *b*	50237 (5542) *a*	0.001
N (kg ha^{-1})	21.6 (9.4) *b*	522 (133) *b*	2052 (482) *a*	0.006
P (kg ha^{-1})	2.1 (0.9) *b*	60.6 (20.2) *b*	176 (32.2) *a*	0.004
K (kg ha^{-1})	3.5 (1.4) *b*	88.3 (27.6) *b*	274 (37.8) *a*	0.001
Macronutrient cations (kg ha^{-1})[2]	32.9 (12.4) *b*	787 (256) *b*	1929 (330) *a*	0.004
Micronutrient cations (kg ha^{-1})[3]	6.6 (4.0) *b*	235 (75,8) *b*	739 (168) *a*	0.007

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
Individual observations per treatment: bladed n=19; burned n=46; no site preparation n=32
[2] sum of Ca, Mg, and K
[3] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 5. Upper and lower mineral soil nutrient concentration under blading, burning, and no site preparation treatments on glaciofluvial plots.[1]

	TREATMENT			
Upper mineral soil:	Blade	Burn	No site preparation	*p* values for treatment differences
C (g kg^{-1})	7.9 (0.9)	8.6 (2.2)	19.4 (11.0)	0.43
N (g kg^{-1})	0.1 (0.0)	0.1 (0.0)	0.3 (0.1)	‡
C:N	42.4 (5.1) *a*	19.2 (4.3) *b*	25.3 (0.58) *ab*	0.014
mineralizable N (mg kg^{-1})	17.4 (0.84)	16.2 (2.5)	38.4 (18.1)	0.22[2]
P (mg kg^{-1})	14.5 (8.5)	2.7 (0.92)	5.4 (2.6)	0.31
Ca (mg kg^{-1})	97.1 (16.5)	254 (54.5)	429 (210)	0.25
Mg (mg kg^{-1})	10.3 (2.4)	28.8 (6.2)	37.0 (12.8)	0.15
K (mg kg^{-1})	18.6 (0.60)	33.8 (5.1)	36.7 (16.4)	0.44
Fe (mg kg^{-1})	18.5 (2.0)	20.8 (7.7)	31.4 (15.2)	0.64
Cu (mg kg^{-1})	0.55 (0.10)	0.73 (0.07)	0.62 (0.12)	0.45
Mn (mg kg^{-1})	1.2 (0.14)	2.0 (0.33)	1.6 (0.83)	0.60
Zn (mg kg^{-1})	0.15 (0.08)	0.29 (0.05)	0.44 (0.09)	0.086
pH ($CaCl_2$)	3.9 (0.13)	3.7 (0.11)	3.8 (0.17)	0.40
Lower mineral soil				
C (g kg^{-1})	12.0 (2.2)	17.6 (2.4)	21.4 (2.8)	0.089
N (g kg^{-1})	0.2 (0.00)	0.6 (0.2)	1.3 (0.5)	0.073
C:N	36.8 (9.3)	27.4 (1.6)	19.4 (3.4)	0.19
mineralizable N (mg kg^{-1})	12.5 (3.5)	22.7 (5.8)	24.7 (5.7)	0.28
P(mg kg^{-1})	18.4 (5.8)	19.6 (7.7)	10.7 (0.94)	0.51
Ca (mg kg^{-1})	56.0 (7.3)	137 (52.9)	246 (126)	0.30
Mg (mg kg^{-1})	4.2 (1.6)	12.9 (3.8)	18.4 (7.0)	0.18
K (mg kg^{-1})	16.2 (1.9)	34.8 (6.2)	26.0 (6.0)	0.11
Fe (mg kg^{-1})	23.6 (7.2)	44.5 (6.6)	25.3 (5.7)	0.11
Cu (mg kg^{-1})	0.49 (0.04)	0.65 (0.06)	0.54 (0.01)	0.086
Mn (mg kg^{-1})	0.37 (0.16)	1.09 (0.21)	0.46 (0.15)	0.051
Zn (mg kg^{-1})	0.06 (0.04)	0.08 (0.06)	0.21 (0.04)	0.15
pH ($CaCl_2$)	4.3 (0.05)	4.1 (0.07)	4.2 (0.05)	0.24

Standard errors of the estimates are shown in parentheses
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
Individual observations per treatment: bladed n=21; burned n=25; no site preparation n=21
‡ Homogeneity of variance not established.
[2] Analysis of variance on log (mineralizable N)

Table 6. Mean nutrient concentration of combined upper and lower mineral soil horizons under blading, burning, and no site preparation treatments on glaciofluvial plots.[1,2]

	TREATMENT			
	Blade	Burn	No site preparation	*p* values for treatment differences
C (g kg^{-1})	10.1 (1.0)	14.8 (2.4)	21.3 (5.9)	0.18
N (g kg^{-1})	0.2 (0.0) *b*	0.5 (0.1) *ab*	0.9 (0.3) *a*	0.046
C:N	39.3 (7.5)	24.6 (1.4)	21.6 (1.7)	0.066
mineralizable N (mg kg^{-1})	14.7 (2.2)	20.6 (4.7)	30.6 (10.7)	0.32
P (mg kg^{-1})	16.6 (7.0)	15.0 (6.4)	9.1 (0.5)	0.62
Ca (mg kg^{-1})	74.9 (11.6)	173 (51.1)	314 (164)	0.30
Mg (mg kg^{-1})	7.0 (2.0)	17.6 (4.0)	25.5 (9.6)	0.18
K (mg kg^{-1})	17.3 (0.85)	34.3 (5.6)	30.8 (10.1)	0.24
Fe (mg kg^{-1})	21.2 (3.2)	37.4 (6.9)	29.1 (4.8)	0.17
Cu (mg kg^{-1})	0.51 (0.07)	0.67 (0.06)	0.57 (0.05)	0.26
Mn (mg kg^{-1})	0.73 (0.07)	1.4 (0.25)	0.92 (0.42)	0.33
Zn (mg kg^{-1})	0.10 (0.06)	0.15 (0.05)	0.30 (0.06)	0.10
pH ($CaCl_2$)	4.1 (0.09)	3.8 (0.08)	4.0 (0.09)	0.27

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
[2] Means of nutrient concentrations in individual horizons, weighted by horizon thickness.

Table 7. Forest floor nutrient concentration and content under blading and burning site preparation treatments on lacustrine plots.

	TREATMENT	
	Blade (n=2 plots)[1]	Burn (n=7 subplots)[2]
C (g kg^{-1})	464 (33.5)	433 (53.0)
N (g kg^{-1})	12.7 (0.8)	13.6 (2.5)
C:N	37.0 (4.8)	34.2 (10.0)
P (mg kg^{-1})	1423 (215)	1471 (315)
Ca (mg kg^{-1})	14374 (1098)	19525 (9482)
Mg (mg kg^{-1})	1869 (747)	1743 (567)
K (mg kg^{-1})	3074 (623)	2888 (711)
Fe (mg kg^{-1})	2201 (1766)	3373 (3592)
Cu (mg kg^{-1})	< 75	< 75
Mn (mg kg^{-1})	1884 (423)	1979 (1548)
Zn (mg kg^{-1})	206 (10.8)	150 (69.8)
C (kg ha^{-1})	901 (78.0)	24583 (3009)
N (kg ha^{-1})	25.1 (5.4)	772 (141)
P (kg ha^{-1})	2.9 (0.9)	83.5 (17.9)
K (kg ha^{-1})	6.2 (2.2)	164 (40.4)
Macronutrient cations (kg ha^{-1})[3]	38.7 (10.8)	1371 (546)
Micronutrient cations (kg ha^{-1})[4]	9.1 (5.6)	312 (242)

[1] Standard errors of the estimates are shown in parentheses
[2] Standard deviations are shown in parentheses
[3] sum of Ca, Mg, and K
[4] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 8. Upper and lower mineral soil nutrient concentration under blading and burning site preparation treatments on lacustrine plots.

	TREATMENT	
	Blade (n=2 plots)[1]	Burn (n=7 subplots)[2]
Upper mineral soil		
C (g kg^{-1})	31.0 (10.1)	38.2 (18.1)
N (g kg^{-1})	2.0 (0.8)	2.7 (2.0)
C:N	20.4 (1.6)	16.8 (4.9)
mineralizable N (mg kg^{-1})	59.6 (21.8)	66.3 (38.1)
P (mg kg^{-1})	10.8 (1.1)	13.3 (10.6)
Ca (mg kg^{-1})	514 (202)	2392 (2499)
Mg (mg kg^{-1})	86.4 (55.0)	136 (82.7)
K (mg kg^{-1})	83.0 (37.5)	92.3 (38.6)
Fe (mg kg^{-1})	58.4 (3.6)	57.6 (25.6)
Cu (mg kg^{-1})	0.6 (0.01)	1.1 (0.3)
Mn (mg kg^{-1})	3.2 (0.7)	4.4 (3.3)
Zn (mg kg^{-1})	0.6 (0.1)	0.8 (0.6)
pH	3.8 (0.1)	4.5 (0.8)
Lower mineral soil		
C (g kg^{-1})	6.7 (0.3)	17.4 (9.5)
N (g kg^{-1})	0.1 (0.1)	0.8 (0.7)
C:N	23.2 (3.8)	19.4 (3.5)
mineralizable N (mg kg^{-1})	6.8 (1.2)	16.0 (16)
P (mg kg^{-1})	18.0 (6.0)	13.4 (9.7)
Ca (mg kg^{-1})	436 (358)	2032 (1519)
Mg (mg kg^{-1})	123 (111)	128 (51.2)
K (mg kg^{-1})	44.5 (25.9)	72.3 (39.3)
Fe (mg kg^{-1})	24.0 (16.0)	21.7 (13.1)
Cu (mg kg^{-1})	0.65 (0.01)	0.85 (0.17)
Mn (mg kg^{-1})	1.4 (1.0)	0.32 (0.50)
Zn (mg kg^{-1})	0.31 (0.01)	0.28 (0.4)

[1] Standard errors of the estimates are shown in parentheses
[2] Standard deviations are shown in parentheses

Table 9. Upper and lower mineral soil nutrient content under blading, burning, and no site preparation treatments on glaciofluvial plots.[1]

	TREATMENT			
	Blade	Burn	No site preparation	*p* values for treatment differences
Upper mineral soil				
C (kg ha^{-1})	11136 (1655)	6106 (897)	18980 (14598)	0.59
N (kg ha^{-1})	126 (3.5)	166 (15.8)	1543 (1390)	0.42
Mineralizable N (kg ha^{-1})	23.4 (2.3)	13.2 (1.0)	36.3 (24.2)	0.62[2]
P (kg ha^{-1})	22.6 (12.4)	2.1 (0.7)	5.7 (3.8)	0.20
K (kg ha^{-1})	26.0 (1.9)	26.4 (2.0)	33.8 (22.9)	0.90[2]
Macronutrient cations (kg ha^{-1})[3]	176 (34.3)	225 (27.2)	447 (325)	0.81[2]
Micronutrient cations (kg ha^{-1})[4]	28.7 (4.1)	17.8 (4.4)	31.0 (20.9)	0.74
Lower mineral soil				
C (kg ha^{-1})	20639 (3247)	31531 (6999)	29041 (5668)	0.40
N (kg ha^{-1})	390 (53.5)	1101 (320)	1858 (720)	0.15
Mineralizable N (kg ha^{-1})	22.8 (5.5)	36.7 (8.7)	32.6 (9.0)	0.48
P (kg ha^{-1})	30.0 (7.5)	38.1 (20.6)	12.8 (2.5)	0.42
K (kg ha^{-1})	28.2 (2.3)	57.0 (14.8)	34.6 (8.8)	0.18
Macronutrient cations (kg ha^{-1})	151 (33.6)	289 (117)	407 (219)	0.50
Micronutrient cations (kg ha^{-1})	46.6 (11.4)	83.9 (17.5)	33.7 (3.4)	0.064

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
Individual observations per treatment: bladed n=21; burned n=25; no site preparation n=21.
[2] Analysis of variance on log (mineralizable N), log (kg ha^{-1} K), and log (kg ha^{-1} macronutrient cations).
[3] sum of Ca, Mg, and K
[4] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 10. Available nutrient content in the soil profile (total forest floor nutrients plus mineral soil total C, total N, Bray P, exchangeable K, exchangeable macronutrient cations, and exchangeable micronutrient cations) under blading, burning, and no site preparation treatments on glaciofluvial plots.[1,2]

	TREATMENT			
	Blade	Burn	No site preparation	*p* values for treatment differences
C (kg ha^{-1})	32578 (3594) *b*	56823 (8049) *ab*	98258 (23158) *a*	0.046
N (kg ha^{-1})	537 (55.0) *b*	1789 (306) *ab*	5454 (2577) *a*	0.005[3]
P (kg ha^{-1})	54.8 (19.2)	101 (39.1)	195 (33.7)	0.052
K (kg ha^{-1})	57.8 (5.3) *b*	172 (38.6) *ab*	343 (64.2) *a*	0.010
Macronutrient cations (kg ha^{-1})[4]	359 (67.5) *b*	1300 (318) *ab*	2783 (829) *a*	0.042
Micronutrient cations (kg ha^{-1})[5]	81.8 (15.1) *b*	336 (77.9) *ab*	804 (184) *a*	0.012

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
[2] Sum of nutrient contents in each horizon
[3] Analysis of variance on log (kg ha^{-1} N)
[4] sum of Ca, Mg, and K
[5] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 11. Nutrient content of combined upper and lower mineral soil under blading, burning, and no site preparation treatments on glaciofluvial plots.[1, 2]

	TREATMENT			
	Blade	Burn	No site preparation	*p* values for treatment differences
C (kg ha^{-1})	31776 (3427)	37638 (7244)	48021 (20149)	0.67
N (kg ha^{-1})	516 (50.2)	1267 (316)	3401.44 (2109)	0.084[3]
mineralizable N (kg ha^{-1})	46.1 (7.8)	50.0 (8.7)	68.9 (33.0)	0.71
P (kg ha^{-1})	52.7 (19.9)	40.2 (20.6)	18.6 (5.0)	0.40
K (kg ha^{-1})	54.2 (4.0)	83.4 (16.4)	68.4 (31.4)	0.63
Exchangeable cations (kg ha^{-1})[4]	326 (60.5)	514 (144)	854 (542)	0.54
Micronutrient cations (kg ha^{-1})[5]	75.2 (12.0)	102 (17.3)	64.7 (17.5)	0.30

Standard errors of the estimates are shown in parentheses.
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
[2] Sum of nutrient contents in each horizon
[3] Analysis of variance on log (kg ha^{-1} N)
[4] sum of Ca, Mg, and K
[5] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 12. Upper and lower mineral soil nutrient content under blading and burning site preparation treatments on lacustrine plots.

	TREATMENT	
	Blade (n=7, 2 sites) [1]	Burn (n=7, 1 site) [2]
Upper mineral soil		
C (kg ha^{-1})	31701 (10358)	36426 (24564)
N (kg ha^{-1})	2019 (715)	2699 (2463)
mineralizable N (kg ha^{-1})	61.2 (22.4)	64.6 (49.7)
P (kg ha^{-1})	11.6 (2.2)	9.5 (5.5)
K (kg ha^{-1})	86.1 (40.1)	75.2 (25.2)
Macronutrient cations (kg ha^{-1})[3]	728 (311)	2324 (2809)
Micronutrient cations (kg ha^{-1})[4]	62.1 (5.2)	56.8 (31.7)
Lower mineral soil		
pH	4.2 (0.06)	4.7 (0.79)
C (kg ha^{-1})	13594 (1986)	35117 (20912)
N (kg ha^{-1})	50.2 (50.2)	1457 (1406)
mineralizable N (kg ha^{-1})	15.2 (3.5)	31.8 (32.1)
P (kg ha^{-1})	36.5 (13.6)	25.7 (16.9)
K (kg ha^{-1})	86.5 (44.9)	143 (65.6)
Macronutrient cations (kg ha^{-1})[3]	1171 (935)	4553 (3684)
Micronutrient cations (kg ha^{-1})[4]	53.6 (33.6)	45.8 (26.6)

[1] Standard errors of the estimates are shown in parentheses
[2] Standard deviations are shown in parentheses
[3] sum of Ca, Mg, and K
[4] sum of DTPA extractable Fe, Mn, Cu, and Zn

Table 13. Foliar element concentration and content of spruce on glaciofluvial bladed and burned plots.[1]

	CONCENTRATION[2]				CONTENT (µg per needle)	
	Blade	Burn	*p* values for treatment differences	Critical value[3]	Blade	Burn
N	13.4 (0.2) *a*	10.9 (0.2) *b*	0.002	15.5	63.2 (1.3)	60.7 (1.8)
P	1884 (78.1) *a*	1614 (18.2) *b*	0.028	1600	8.9 (0.3)	9.0 (0.4)
K)	5614 (127)	5556 (180)	0.81	4500	26.5 (0.4)	30.8 (0.4)
Ca	4857 (178)	3963 (362)	0.091	2000	22.8 (0.4)	21.9 (1.3)
Mg	872 (23.3)	770 (47.1)	0.12	1200	4.1 (0.04)	4.3 (0.4)
Fe	37.6 (19.2)	69.5 (19.6)	0.31	50	0.18 (0.09)	0.40 (0.13)
Zn	92.5 (14.6) *a*	26.9 (8.1) *b*	0.017	15	0.43 (0.07)	0.15 (0.05)
Mn	641 (38.6)	547 (67.2)	0.29	25	3.0 (0.2)	3.1 (0.5)
Al	143 (18.1)	159 (17.6)	0.55		0.68 (0.10)	0.91 (0.16)
Cu	< 75	< 75				

Standard errors of the estimates are shown in parentheses
Means followed by different letters are different at ∝ =0.05
[1] Values are means of three replicate plots per treatment.
[2] Values for concentration are in g kg^{-1} for N; mg kg^{-1} for P, K, Ca, Mg, Fe, Zn, Mn, Al, and Cu
[3] From Ballard and Carter 1985

Table 14. Foliar element concentration and content of spruce on lacustrine bladed and burned plots.

	CONCENTRATION[1]			CONTENT (µg per needle)	
	(n=13 over 2 sites) Blade[2]	(n=7, 1 site) Burn[3]	Critical value[4]	Blade[1]	Burn[2]
N	13 (0.2)	11 (1.0)	15.5	60.9 (3.6)	60.7 (7.1)
P	1907 (77.0)	1534 (135)	1600	8.9 (0.06)	8.6 (1.0)
K	5934 (208)	6340 (652)	4500	27.7 (2.3)	35.5 (5.3)
Ca	4765 (113)	5057 (718)	2000	22.2 (1.6)	28.2 (3.8)
Mg	776 (32.4)	697 (63.1)	1200	3.6 (0.31)	3.9 (0.41)
Fe	85.8 (23.2)	145 (67.5)	50	0.39 (0.09)	0.80 (0.37)
Zn	63.7 (31.5)	115 (33.3)	15	0.28 (0.13)	0.65 (0.16)
Mn	574 (156)	249 (116)	25	2.7 (0.86)	1.4 (0.72)
Al	153 (13.6)	112 (32.3)		0.71 (0.03)	0.63 (0.20)
Cu	< 75	< 75			

[1] Values for concentration are in g kg^{-1} for N; mg kg^{-1} for P, K, Ca, Mg, Fe, Zn, Mn, Al, and Cu
[2] Standard errors of the estimates are shown in parentheses
[3] Standard deviations are shown in parentheses
[4] From Ballard and Carter 1985

Table 15. Spruce productivity on bladed and burned glaciofluvial and lacustrine plots[1]

	TREATMENT		
	Blade	Burn	*p* values for treatment differences
Glaciofluvial plots			
Mean internode length above breast height (cm)	35.3 (1.4) *a*	27.8 (0.28) *b*	< 0.001
Mean height at breast height age 5 yr (m)	3.2 (0.06)	2.8 (0.01)	0.56
Lacustrine plots			
Mean internode length above breast height (cm)	34.9 (0.75)	30.2 (4.6)	na
Mean height at breast height age 5 yr (m)	3.2 (0.01)	2.9 (0.21)	na

Standard errors of the estimates are shown in parentheses
Means followed by different letters are different at $\propto$ =0.05
[1] Values are means of three replicate plots per treatment.
na = not applicable

Table 16. Relationships between nutrient content of forest floor and mineral soil[1] of bladed and burned glaciofluvial and lacustrine soils (x) and foliar nutrient concentration (y): r^2 values of simple linear regressions and nature of relationship (+/-).

	Foliar nutrient concentration		
Soil nutrient content (kg ha^{-1})	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
Glaciofluvial soils[2]			
C	0.069 (-)		
N	0.13 (-)		
P		0.039 (-)	
K			0.009 (+)
Lacustrine soils[3]			
C	0.56 (-)		
N	0.42 (-)		
P		0.66 (+)	
K			0.56 (-)

[1] Nutrient contents are the sum of forest floor and mineral soil nutrient contents to rooting depth
[2] n=46
[3] n=20

Table 17. Relationships between nutrient status of bladed and burned glaciofluvial and lacustrine mineral soils (x)[1] and foliar nutrient concentration (y): r^2 values of simple linear regressions and nature of relationship (+/-) .[2]

	Foliar nutrient concentration		
	N (g kg^{-1})	P (mg kg^{-1})	K (mg kg^{-1})
Glaciofluvial soils (nutrient concentration)[2]			
C (g kg^{-1})	0.015 (-)		
N (g kg^{-1})	0.086 (-)		
mineralizable N (mg kg^{-1})	0.012 (-)		
P (mg kg^{-1})		0.002 (-)	
K (mg kg^{-1})			0.015 (+)
C:N	0.082 (+)		
N:P	0.081 (-)	0.076 (-)	
Glaciofluvial soils (nutrient content kg ha^{-1})[2]			
C	0.014 (+)		
N	0.033 (-)		
mineralizable N	0.037 (+)		
P		0.003 (+)	
K			0.043 (+)
Lacustrine soils (nutrient concentration)[3]			
C (g kg^{-1})	0.35 (-)		
N (g kg^{-1})	0.28 (-)		
mineralizable N (mg kg^{-1})	0.15 (-)		
P (mg kg^{-1})		0.040 (-)	
K (mg kg^{-1})			0.10 (-)
C:N	0.15 (+)		
N:P	0.13 (-)	0.048 (+)	
Lacustrine soils (nutrient content kg ha^{-1})[3]			
C	0.32 (-)		
N	0.32 (-)		
mineralizable N	0.080 (-)		
P		0.094 (-)	
K			0.10 (-)

[1] Nutrient concentrations are means of mineral soil nutrient concentrations weighted by horizon thickness; nutrient contents are sums of mineral soil nutrient contents to rooting depth.
[2] n=46
[3] n=20

Table 18. Relationships between foliar and soil nutrient status (x) and spruce growth (y) on glaciofluvial and lacustrine soils: r^2 values of simple linear regressions and nature of relationship (+/-) .

	Mean internode length above breast height (cm)	
	Glaciofluvial plots[1]	Lacustrine plots[2]
Foliar nutrient[3]		
N (g kg^{-1})	0.45 (+)	0.053 (+)
P (mg kg^{-1})	0.35 (+)	0.39 (-)
K (mg kg^{-1})	0.026 (+)	0.35 (+)
Soil nutrient concentration		
C (g kg^{-1})	0.046 (-)	0.117 (-)
N (g kg^{-1})	0.15 (-)	0.031 (-)
mineralizable N (mg kg^{-1})	0.072 (-)	0.041 (-)
P (mg kg^{-1})	0.010 (+)	0.068 (+)
K (mg kg^{-1})	0.22 (-)	0.079 (-)
C:N	0.071 (+)	0.054 (+)
N:P	0.049 (-)	0.005 (-)
Soil nutrient content (kg ha^{-1})[3]		
C	0.002 (-)	0.19 (-)
N	0.071 (-)	0.077 (-)
mineralizable N	0.003 (-)	0.057 (-)
P	0.015 (+)	0.032 (+)
K	0.091 (-)	0.14 (-)
exchangeable cations	0.058 (-)	0.042 (-)
micronutrient cations	0.019 (-)	0.007 (-)
Total forest floor and mineral soil content (kg ha^{-1})[4]		
C	0.17 (-)	0.027 (-)
N	0.19 (-)	0.12 (-)
P	0.078 (-)	0.20 (-)
K	0.38 (-)	0.29 (-)
Macronutrient cations	0.32 (-)	0.059 (-)
Micronutrient cations	0.37 (-)	0.18 (-)

[1] n=46
[2] n=20
[3] Nutrient concentrations are means of mineral soil nutrient concentrations weighted by horizon thickness; nutrient contents are the sum of mineral soil nutrient contents to rooting depth.
[4] Nutrient contents are the sum of forest floor and mineral soil nutrient contents to rooting depth.