SOIL NUTRIENT AND ORGANIC MATTER RESPONSES TO FIRE, HARVESTING, AND SALVAGE LOGGING: CHISHOLM FIRE

Progress Report Prepared for
Foothills Model Forest

B. E. Kishchuk

Northern Forestry Centre
Canadian Forest Service

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INTRODUCTION

Protection of soils, site fertility, and site productivity are of fundamental importance for fire and forest management planning. Soil disturbance results in changes in nutrient availability that may affect both short and long-term site productivity. Many aspects of nutrient cycling in boreal soils are related to the accumulation and decomposition of soil organic matter, and natural and anthropogenic disturbances such as fire and harvesting may result in changes to the physical, chemical, and microbiological properties of surface organic materials such as the forest floor and woody debris. These organic materials are an important source of organically bound and adsorbed nutrients, a source of carbon required by microorganisms for decomposition; they provide habitat for microorganisms and have important thermal and hydrological properties. Disturbance or removal of these materials by consumption in fire or other means may substantially alter patterns of nutrient cycling, decomposition, and surface hydrology. Following vegetation-removing disturbance such as fire, a greater proportion of carbon and nitrogen is retained in the forest floor, and maintenance of surface organic materials is important in maintaining nutrient cycling processes (Clinton et al. 1996).

Woody debris and its decomposers are also important in the accumulation and turnover of soil organic matter. Differences in the quantity, size, distribution, and decomposition rates of woody debris may vary between fire and harvesting (Tinker and Knight 2000; Pedlar et al. 2002). These differences may have implications for the maintenance of nutrient cycling and site productivity under forest management scenarios where management of surface materials is a consideration, such as in fuel management or emulation of natural disturbance.

The Chisholm Fire has been identified as being outside the range of natural variability for boreal fires. Loss and recovery of carbon and nutrient pools after fire is a function of fire severity (Clinton et al. 1996). It is essential to characterize the immediate and longer-term impacts of intense fires such as this on soil organic matter and nutrient cycling processes. Information is required to address the sensitivity of soils both in relation to severe fires outside the range of natural variability and to fires in relation to emulation of natural disturbance by harvesting practices. In addition, the combined effects of multiple natural disturbances, or natural and anthropogenic disturbances may be cumulative. Multiple fires, fire on harvested areas, and salvage logging on burned areas are all scenarios that may occur in the boreal mixedwood and for which the scientific basis for the management of surface organic materials is required. This information will be applicable to the identification of sensitive sites and avoidance of site degradation, improving predictive capability of site productivity, and improving and implementing management plans and forest practices that incorporate emulation of natural disturbance.

STUDY OBJECTIVES

This study was initially developed to evaluate and compare the impacts of natural and harvesting-based disturbance on forest floor properties, soil organic matter, nutrient availability, and site productivity in a controlled and replicated study. This would allow an evaluation of disturbance effects on soil organic matter, nutrient cycling, and productivity within similar sites and time frames, rather than as a chronosequence. Through subsequent linkages developed through collaboration with two doctoral students at the University of Alberta (Tyler Cobb and Michael Simpson) the opportunity has arisen to investigate the role of saproxylic beetle and bryophyte communities on the decomposition of woody debris and nutrient turnover. The biological mechanisms by which nutrient availability is influenced by the decomposition of coarse woody debris is poorly understood, especially under disturbance. Under the collaborative work we are able to explore more fully the impacts of different disturbance types on woody debris properties, and mechanisms of organic matter and nutrient turnover on these sites.

The objectives of the ongoing collaborative work are listed below:

1. To characterize surface organic matter properties (including size, distribution, and decomposition rates of woody debris) under different disturbance types (burning, harvesting, salvage logged, undisturbed).
2. To identify relationships among surface organic matter, nutrient availability, foliar nutrition and productivity of regenerating stands under these disturbance types.
3. To identify the role of saproxylic beetle and bryophyte communities in the decomposition of coarse woody debris and turnover of nutrients.

In the first year this study received funding from the Foothills Model Forest, establishment of long-term research installations was completed and characterization of soil nutrient and organic matter (B. Kishchuk: analyses in progress) and coarse woody debris properties (T. Cobb: completed) under disturbance was initiated.

The focus of this report is the first-year soil organic matter and nutrient component of the study, in which responses of soil properties to disturbance are being determined. Long-term monitoring installations and plots were established in 2001 and 2002, and soils were sampled in these plots to determine changes in soil properties immediately following disturbance. These early results will provide information on short-term responses to disturbance, and will provide baseline information to be used for following the effects of these disturbances over the longer term. Soil sample analysis is continuing at present at the Northern Forestry Centre Analytical Services Laboratory, with the anticipated completion date of these analyses being late summer 2003. This report will present results from analyses available to date.

As part of the larger integrated study, two additional studies have been established to date. A study on nutrient dynamics and decomposition rates of fine woody debris was established in 2002 (B. Kishchuk), with 1-year data to be collected in late 2003. A study of decomposition rates of coarse woody debris and changes in surrounding soil nutrients was established in 2002 (T. Cobb), with 1-year data to be collected in 2003.

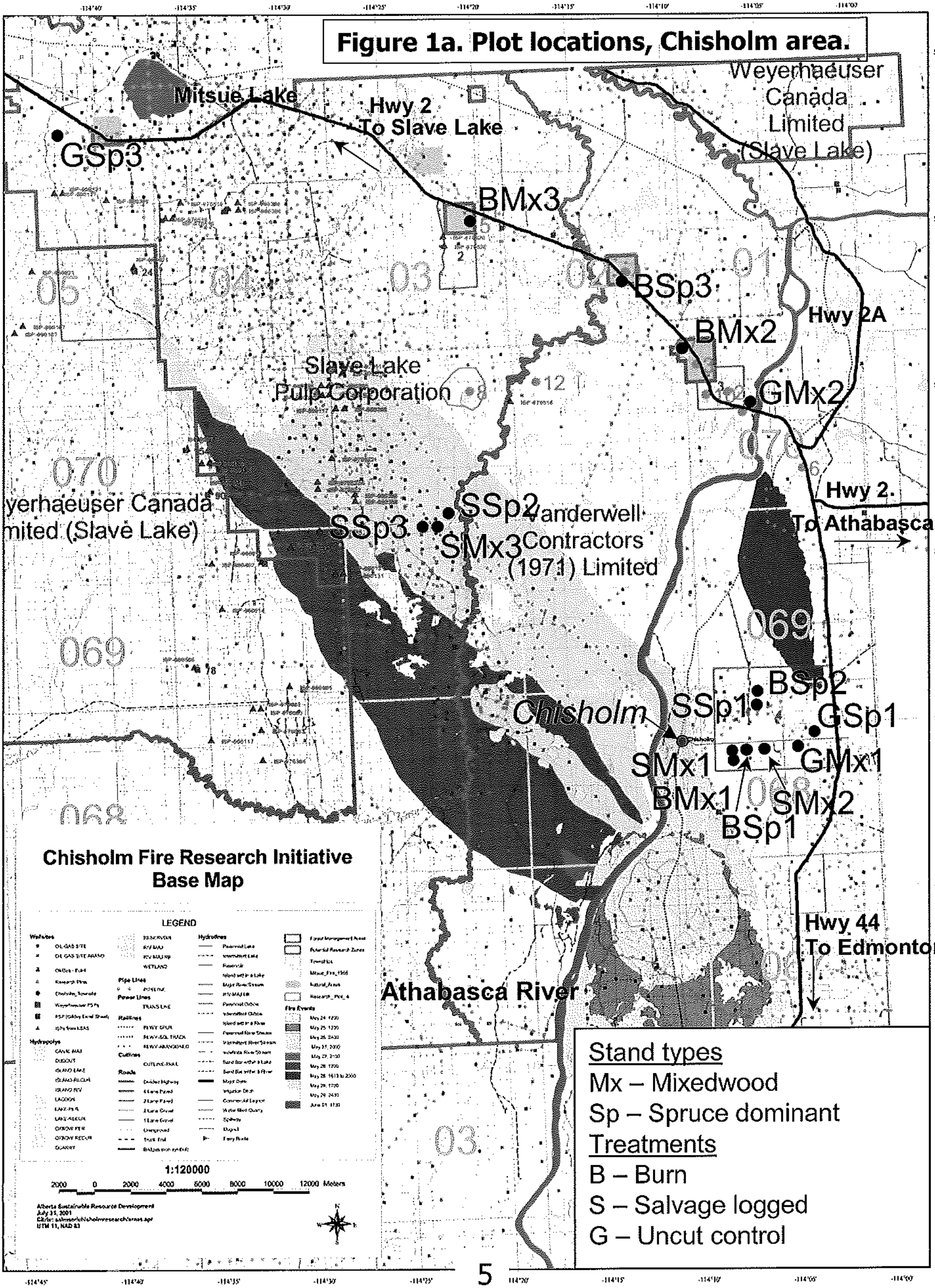
A third integrated field mesocosm study investigating woody debris, nutrient cycling, saproxylic beetles, and bryophyte communities will be established in 2003 (work to be conducted by B. Kishchuk, T. Cobb, M. Simpson).

METHODS

Site Selection, Plot Establishment, and Soil Sampling

Field sites were selected and research plots established in 2001 and 2002 in the Chisholm, Slave Lake, and Canyon Creek regions (Fig.1a and 1b). Soils were sampled within the first year following disturbance. Study sites were established in four disturbance types and two stand cover types. Disturbance types or treatments were burned, salvage logged, clearcut harvested, or uncut, undisturbed control sites.

Figure 1a. Plot locations, Chisholm area.



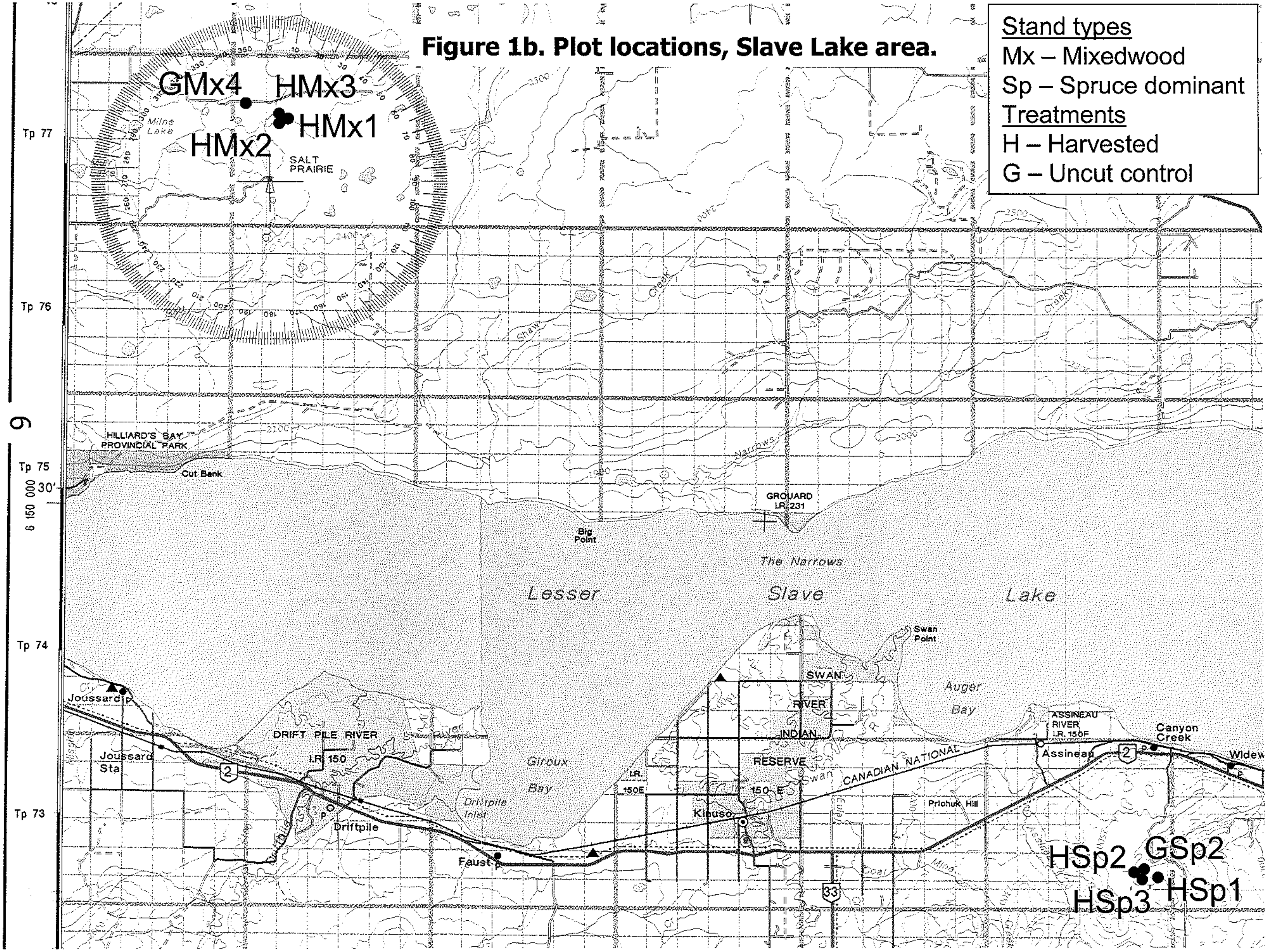


Figure 1b. Plot locations, Slave Lake area.

1. Burned sites

- burned in Chisholm Fire, May 2001 and not previously burned in other recent fires
- plots established and soils sampled September-October 2001

2. Salvage logged sites

- salvage-logged winter of 2001-2002 following the Chisholm Fire
- plots established and soils sampled July-August 2002

3. Clearcut harvested sites

- green timber harvested winter 2001-2002
- plots established and soils sampled July-August 2002

4. Uncut, undisturbed control sites

- standing green timber
- plots established and soils sampled July-August 2002

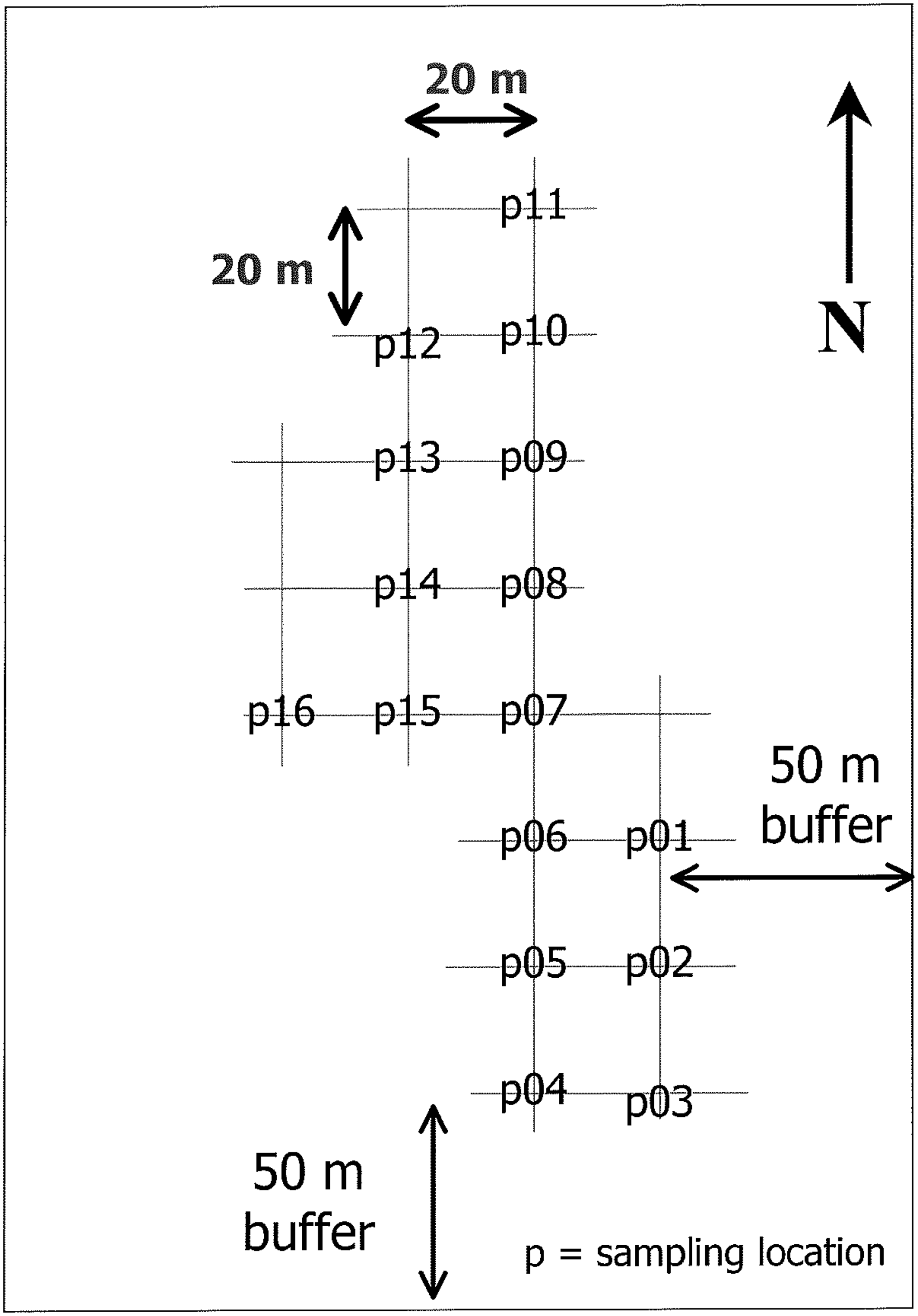
Cover types were **white spruce dominated** and **white spruce-deciduous mixedwoods**. Stands were identified using the Alberta Vegetation Inventory, and only sites deemed productive based on composition, density, and size of trees in the stand were selected for the study. For all treatments, spruce stands previously or currently contained at least 80% white spruce. Mixedwood stands contained between 60% and 40% white spruce, and between 40% and 60% trembling aspen or balsam poplar. Stands with 51-70% crown closure ('C' density) and tree height 25 m were preferred candidate stands, and only stands meeting these criteria were selected. Two burned mixedwood stands and one burned spruce stand are within provincially designated and protected Natural Areas.

Each disturbance (4) and cover type (2) combination was replicated 3 times (total 24 stands). Study sites were approximately 2 ha in size. The 2-ha area contained a soil sampling grid of approximately 1 ha, as well as a surrounding area used for coarse woody debris assessments, fine woody debris assessment and decomposition study, and invertebrate sampling (T. Cobb). Soils were sampled using a grid layout (Fig. 2). Grid intersections were located at 20 m by 20 m intervals in each direction. Each grid contained 16 sampling points. Sample points on the grid transects were numbered running north to south and south to north in a snaking fashion, moving from east to west. Grids were configured to maximize the area for the shape of the stand and to encompass representative soil, landform, and vegetation features.

Soils were sampled following plot establishment at the burned sites in 2001 and in the remaining treatments in 2002. Soils were sampled at all 16 grid points in the burned plots in 2001; however, sampling intensity was reduced to 10 of the 16 sampling points (randomly chosen) for the remaining 3 treatments in 2002. Sample coordinate points were recorded by global positioning system (GPS). Approximately 1 ha of area (50 m) remains around each sampling grid as a buffer area.

Forest floor (combined L, F, and H horizons) samples were taken for chemical analysis at each sampling location. Forest floor depth at 4 corners of a 15 x 15 cm quadrat was measured and averaged to provide a mean for each sample. Forest floor mass was determined by sampling the entire depth of the forest floor within the quadrat. Oven-dry weight of the forest floor was used to determine bulk density and carbon content (measured in kilograms per hectare). Surface mineral soil (0-7 cm) samples were taken at each sampling location for chemical analysis, and a 500 cm^3 soil core was taken to determine bulk density.

Figure 2. Generalized plot layout.



Soil Analysis

Forest floor and mineral soils were analyzed for pH (in $CaCl_2$), total carbon, cation exchange capacity, exchangeable cations, total nitrogen (N), extractable phosphorus, extractable sulphur, and mineral soil particle size analysis, following the methods of Kalra and Maynard (1991).

An 8-week laboratory incubation of net mineralizable N in forest floor and mineral soil samples was established in August 2002 and completed in October 2002. Methods for the incubation study are given in Appendix 1. Extractable nitrate-N (NO_3-N) and ammonium-N (NH_4-N) were determined as the initial extractable N values in the net N mineralization study. At present, results of pH, total carbon, extractable and mineralizable NO_3-N and NH_4-N, and bulk density are available and will be presented here.

Statistical Analysis

All statistical analyses were performed on Statistical Analysis Systems (SAS) (SAS Institute 2001). Prior to statistical analysis, all data were tested to meet assumptions of normality and homogeneity of variance. Normality was determined by plotting the residual values of the dependant variable in distribution and normal probability plots, which were assessed according to appearance. The Shapiro-Wilk statistic was also used to determine normality, with values greater than 0.8 seen as indicating normality. Levene's test for homogeneity was used to assess whether the data contained equal variances, grouping by both stand type and by treatment individually. When data did not meet these criteria the appropriate transformation was used to ensure normality and homogeneity of variance for stand type and treatment. Transformations used in the data analysis are given in Appendix 2.

Two-way analysis of variance was performed using the general linear model in SAS (PROC GLM) to determine the effects of treatments on soil properties. Analysis was done on transformed data where required. Where there was no statistically significant treatment-stand type interaction, the effects of treatment across both stand types, and the effects of stand type across all treatments were considered (statistical main effects). These cases provide the broadest interpretation of the treatment and stand type effects, and these results are presented as treatment means over both stand types, or as stand type means over all treatments. Unless otherwise indicated, means presented graphically are in this manner.

In some cases, however, the effects of disturbance treatments were not consistent across stand types. In cases where a significant treatment-stand type interaction existed, treatment effects were considered individually within each stand type. These results are presented as the means of each treatment-stand type combination and are indicated accordingly. All results are reported as arithmetic means with a significance level of $\alpha = 0.05$.

Mean separation was performed using least-squares means with Tukey adjustment or Tukey-Kramer when sample size was unequal. For significant interaction effects, simple effects were analyzed and means comparisons completed using the Tukey or Tukey-Kramer adjustment.

Analysis of covariance was performed on mineralizable N data. Post-storage values were used as initial values in calculating net mineralizable NO_3-N and NH_4-N. This post-storage value was used as the covariate. Results from this analysis were reported as the adjusted LS means and standard deviations. Mean separation followed as outlined above.

Sample sizes are frequently uneven in these analyses due to two factors. First, sampling at the establishment of the burn plots in 2001 was done at an intensity of 16 sampling locations per site. Sampling intensity was modified in the remaining treatments to 10 sampling locations in 2002. In addition, the forest floor was absent in many of the burned and salvage-logged sites, and as a result there are many missing values in these analyses.

RESULTS

Differences in Soil Properties Between Undisturbed Stand Types

Soil properties in uncut (control) spruce and mixedwood stands are shown in Table 1. This information is provided to illustrate that there are inherent differences in soil properties between the two stand types in this study in the absence of the disturbance treatments. The implications of this are that a treatment may have different results in different stand types, i.e., the effects of treatment varies with stand type. Statistically, this is referred to as a treatment-stand type interaction. Differences in soil properties between uncut controls in the two stand types were analyzed using a t-test and are shown in Table 1.

Table 1. Soil properties in uncut control mixedwood and spruce stands

Forest Floor	**Mixedwood**	**Spruce**
Depth (cm)	10.1 (1.3) **a**	6.9 (0.6) **b**
Mass (g/m^2)	8545 (1327) **a**	4528 (375) **b**
Bulk density (g/cm^3)	0.081 (0.004) **a**	0.067 (0.004) **b**
pH	5.33 (0.10)	5.09 (0.11)
Carbon concentration (%)	43.6 (1.0) **b**	46.9 (0.4) **a**
Carbon content (kg/ha)	38277 (6056) **a**	21266 (1802) **b**
Extractable NO_3-N (μg/g)	2.69 (0.18) **b**	16.08 (5.72) **a**
Extractable NH_4-N (μg/g)	23.23 (3.31) **b**	54.20 (8.28) **a**
Net mineralizable NO_3-N (μg/g)	99.15 (22.70)	178.12 (46.34)
Net mineralizable NH_4-N (μg/g)	245.23 (43.74)	319.27 (55.56)
Mineral Soil	**Mixedwood**	**Spruce**
Bulk density (g/cm^3)	0.8 (0.06)	0.8 (0.03)
pH	4.45 (0.10) †	4.14 (0.13) †
Carbon concentration (%)	4.0 (0.4) †	4.0 (0.4) †
Carbon content (kg/ha)	24659 (2570) †	20677 (1759) †
Extractable NO_3-N (μg/g)	2.0 (0.4)	1.4 (0.3)
Extractable NH_4-N (μg/g)	5.7 (0.2) **b**	8.8 (1.2) **a**
Net mineralizable NO_3-N (μg/g)	21.6 (7.0) ‡ **a**	3.7 (1.5) ‡ **b**
Net mineralizable NH_4-N (μg/g)	14.2 (3.1) ‡	12.0 (2.8) ‡

n = 30 unless otherwise indicated: † n = 24; ‡ n = 29.
Standard errors are shown in parentheses.
Different letters indicate significant stand-type differences at $\alpha = 0.05$.

Forest floor depth, mass, and bulk density were significantly greater in the mixedwood stands than in the spruce stands. Greater forest floor depth and mass in the mixedwood stands may be due to either higher rates of litter input, lower rates of decomposition, or both. There was no difference in forest floor pH between the two stand types, in contrast to findings from other Alberta mixedwood-spruce studies in which forest floor pH was lower in coniferous stands than in mixedwood stands (Kishchuk 2002). Carbon concentration (%) was significantly greater in spruce stands than in mixedwood stands. However, carbon content (kg/ha) was greater in mixedwood stands, reflecting the greater forest floor depth and mass in the mixedwood stands.

Extractable NO_3-N and NH_4-N were both significantly greater in spruce stands than in mixed wood stands. There was no difference in net mineralizable NO_3-N or NH_4-N between the two stand types.

There were no differences in surface mineral soil (0-7 cm depth) bulk density, pH, carbon, extractable NO_3-N, or net mineralizable NH_4-N between undisturbed conditions of the two stand types. Extractable NH_4-N was significantly greater in the spruce stands than in the mixedwood stands, while net mineralizable NO_3-N was greater in the mixedwood stands.

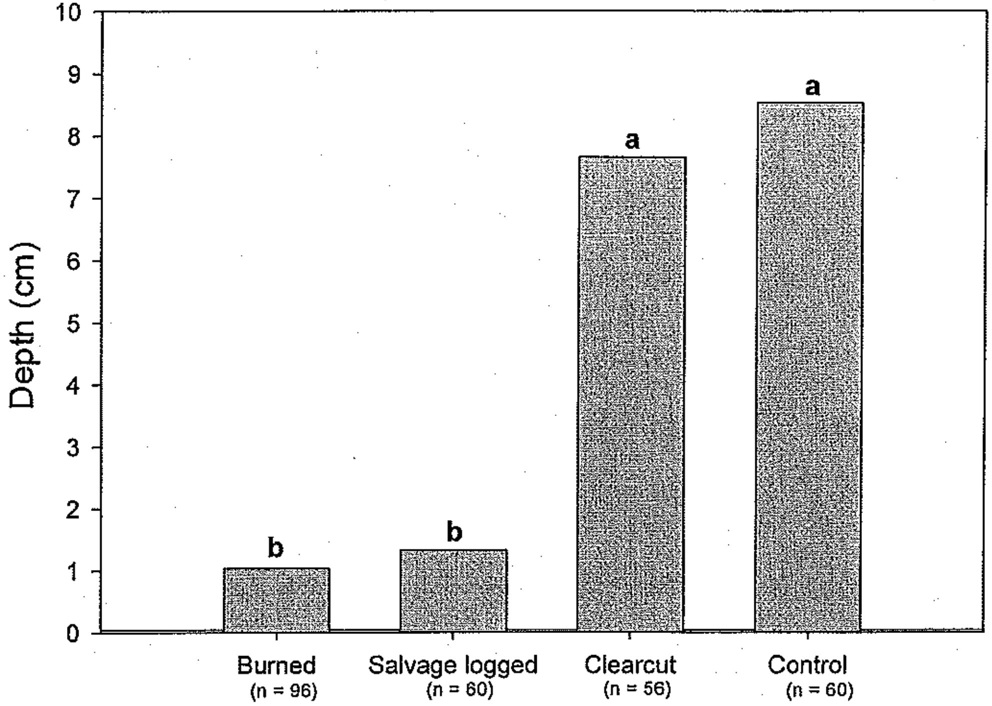
Disturbance Treatment Effects on Soil Properties

Forest Floor Properties

Forest Floor Depth

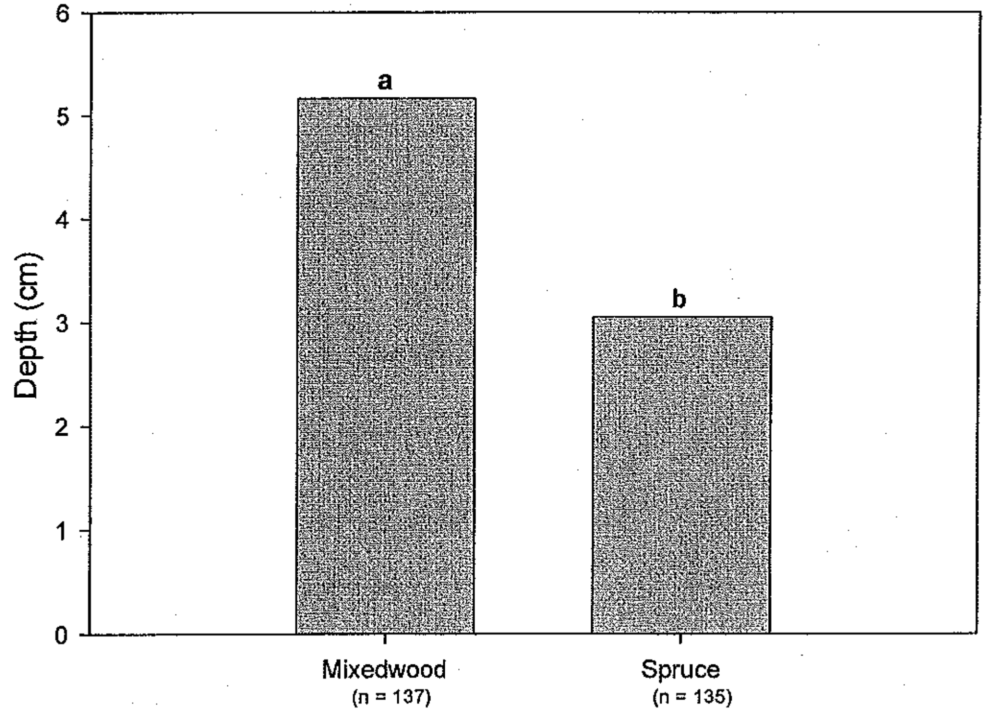
Treatment means of forest floor depth are presented in Figure 3. Forest floor depth was significantly reduced in the burn and salvage-logged treatments relative to the clearcut and control treatments, as a result of the complete consumption of the forest floor at many locations. There was no difference in forest floor depth between the uncut control and clearcut treatments in the first year following harvest. Forest floor depth was significantly greater in mixedwood stands than in spruce stands across all treatments (Fig. 4), the same trend that was evident when only the uncut controls were considered (Table 1).

Figure 3. Forest floor depth in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at α = 0.05.

Figure 4. Forest floor depth in mixedwood and spruce stands.

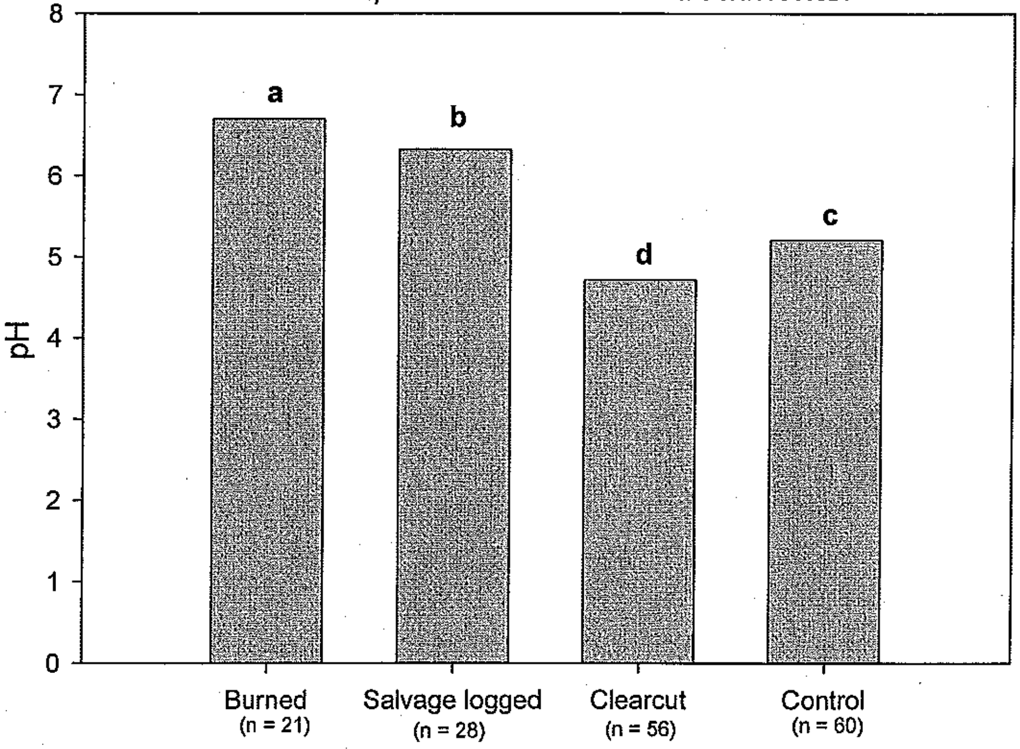


Different letters indicate stand-type differences at α = 0.05.

Forest Floor pH

Forest floor pH was greatest in the burn treatment and lowest in the clearcut, with significant differences among all treatments (Fig. 5). Greater pH in the burn and salvage-logged treatments relative to the control is not unexpected due to the production of alkaline oxides of Ca, Mg, and K under fire. Forest floor pH was significantly greater in the burn treatment than in the salvage-logged treatment; however, the reason for this difference is not known. The lower pH in the clearcut relative to the uncut control may be due to differences in decomposition processes. There was no difference in forest floor pH between the two stand types.

Figure 5. Forest floor pH in burned, salvage-logged, clearcut, and uncut control treatments.

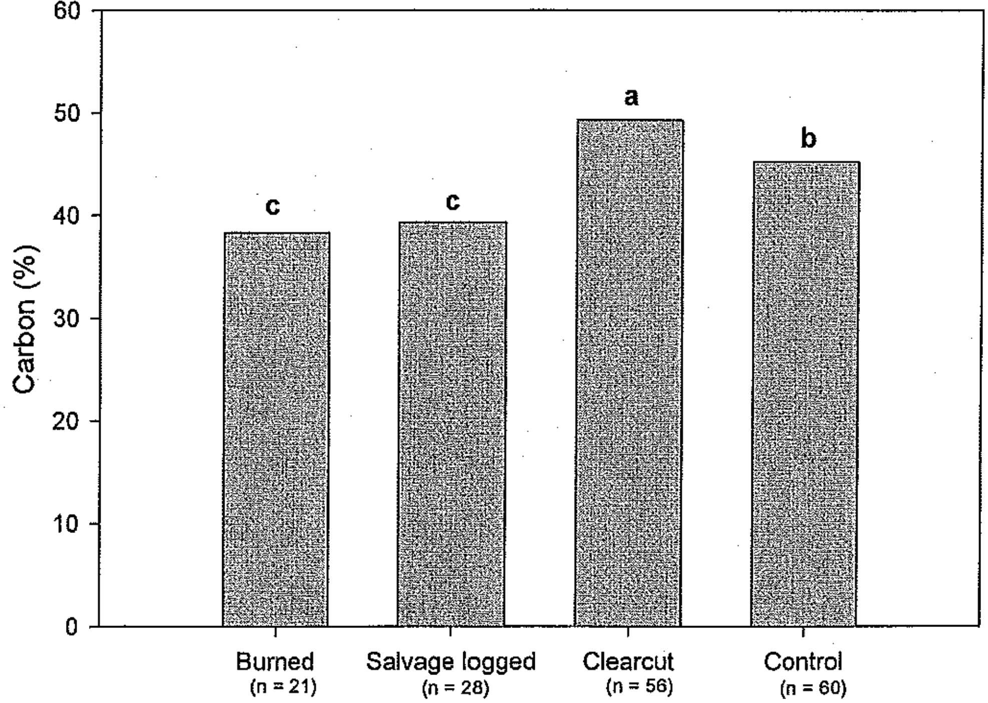


Different letters indicate treatment differences at $\alpha = 0.05$.

Forest Floor Carbon

Forest floor carbon concentration was lower in the burn and salvage-logged treatments than in the control and clearcut treatments (Fig. 6). Lower carbon concentrations in the burn and salvage-logged treatments likely result from combustion of surface organic materials, oxidation of organic carbon, and release of carbon as carbon dioxide. Greater carbon concentrations in the forest floor in the clearcut than in the control may be due to slash inputs under harvesting. There was no difference in carbon concentration between stand types.

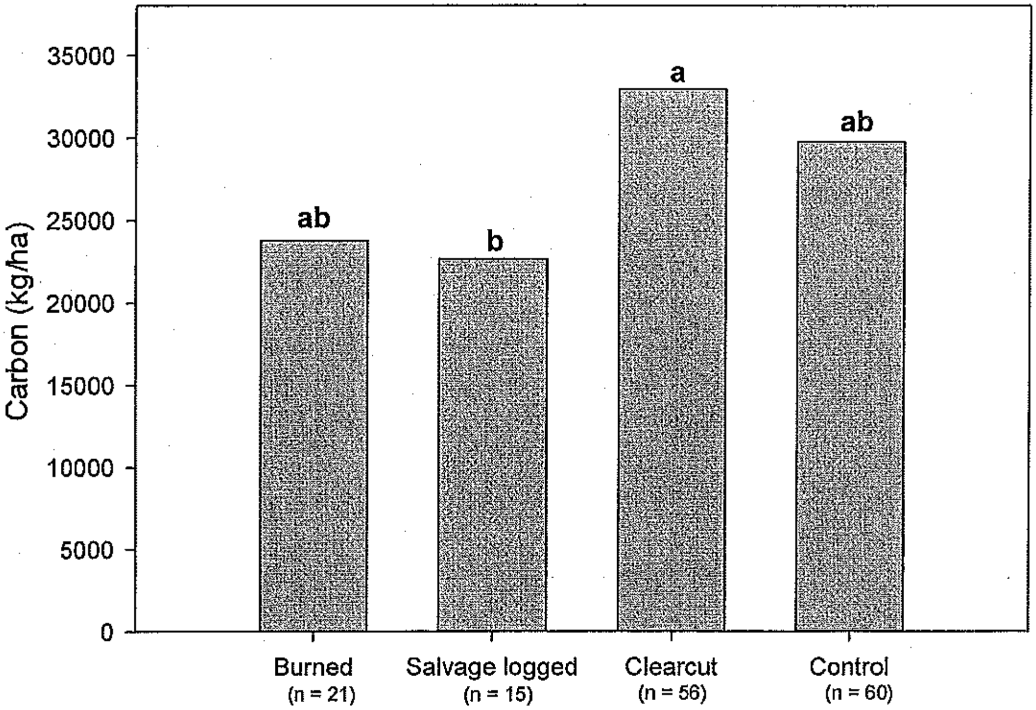
Figure 6. Forest floor carbon concentration in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

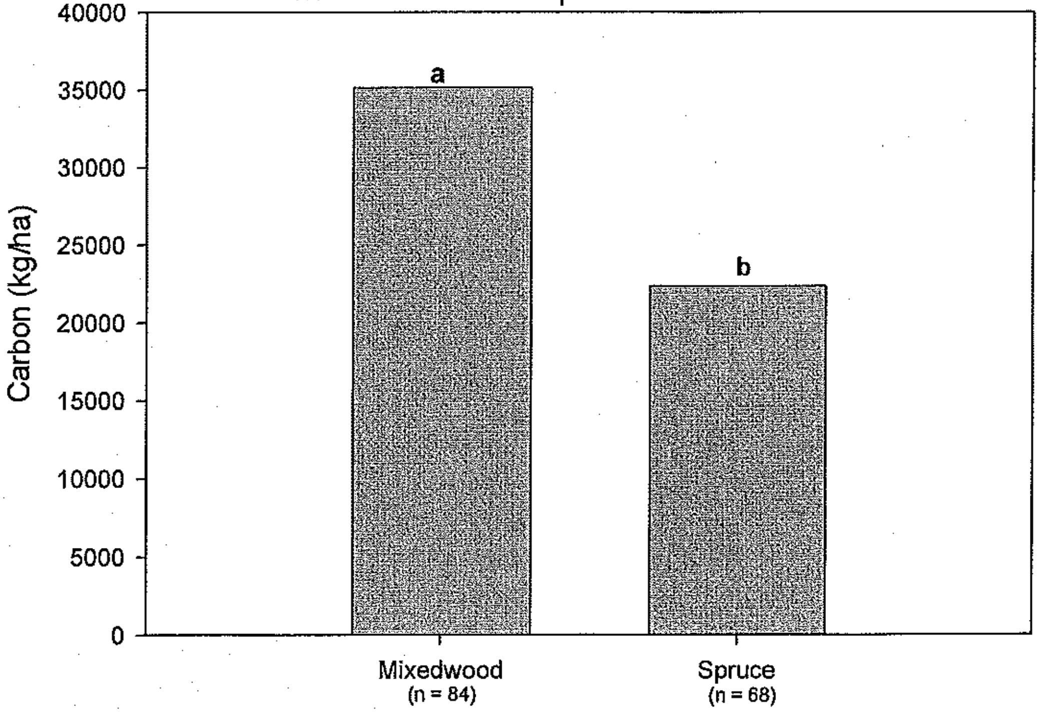
Carbon content (kilograms per hectare) was greatest in forest floors in the clearcut treatment, lowest in the salvage-logged treatment, and intermediate in the control and burn treatments (Fig. 7). The greatest carbon content in the clearcut is a function of both the greatest carbon concentration, and a greater forest floor depth than in the burn and salvage treatments. Simard et al. (2001) found greater nutrient contents in the forest floor of harvested boreal stands than burned stands. These authors suggested that slower, but more sustained rates of nutrient release may occur in the harvested stands with greater forest floor nutrient contents, whereas more pronounced but shorter duration increases in nutrient availability may be occurring under burning. On the basis of the available data in this study it is evident that there is a trend toward greater forest floor organic matter content in the harvested stands than in the burn treatment, with some significant differences occurring. However, the remainder of the soil nutrient data is required to determine whether nutrient, as well as carbon contents, were greater under harvesting than under burning. Mixedwood forest floors had a significantly greater carbon content than spruce forest floors (Fig. 8).

Figure 7. Forest floor carbon content in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at α = 0.05.

Figure 8. Forest floor carbon content in mixedwood and spruce stands.



Different letters indicate stand-type differences at α = 0.05.

Forest Floor Extractable and Mineralizable Nitrogen

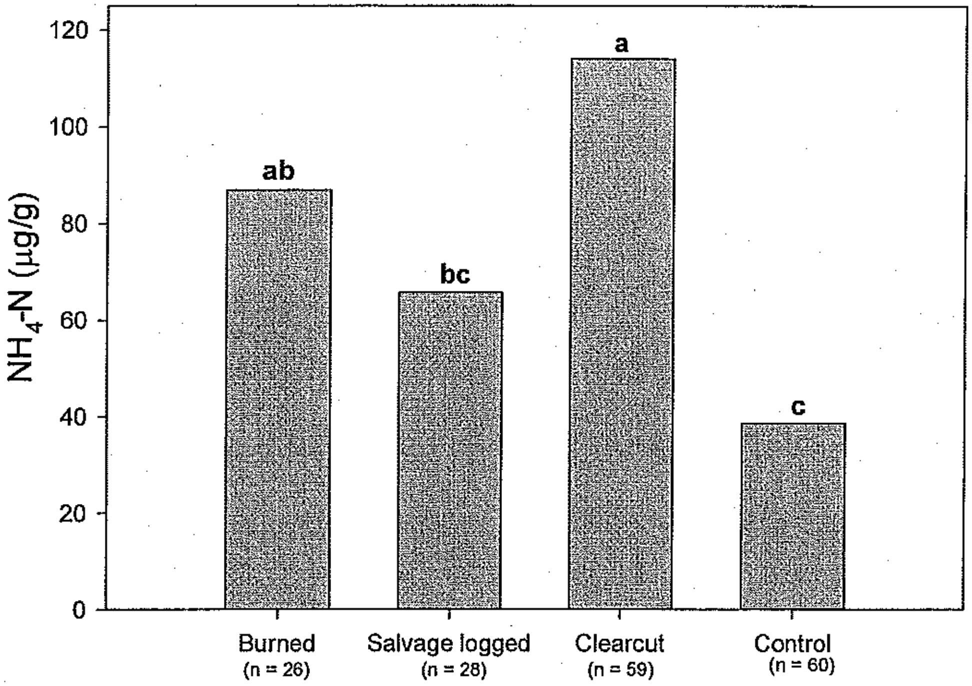
Nitrogen in inorganic (mineral) forms (NH_4-N and NO_3-N) is the main source of nitrogen available to plants. However, most soil N occurs in organic forms resulting from plant, animal, and microbiological detritus that are unavailable to plants. Concentrations of extractable NH_4-N and NO_3-N indicate the pool sizes of available N forms at a particular time.

The microbial conversion of organic N to inorganic N is termed N mineralization. Nitrogen mineralization is controlled by a complex interaction of factors such as temperature, moisture, microbial populations, carbon sources, the nature of the organic nitrogen source, and other soil chemical conditions, such as pH. Mineralized N is also re-utilized, or immobilized, by the microorganisms involved. Thus estimates are made of net mineralization, or the total mineralized, less what is immobilized (net mineralization = gross mineralization - immobilization). Nitrogen mineralization rates are an index of nitrogen availability, or the amount of soluble, mineral N available to plants. As nitrogen is most frequently limiting, the retention and release of nitrogen in available forms is of primary interest in maintaining site productivity.

Extractable NH_4-N and NO_3-N

Extractable NH_4-N concentration was greater in all disturbance treatments than in the uncut control (Fig. 9). Extractable NH_4-N was significantly greater in the clearcut and burn treatments than in the uncut control.

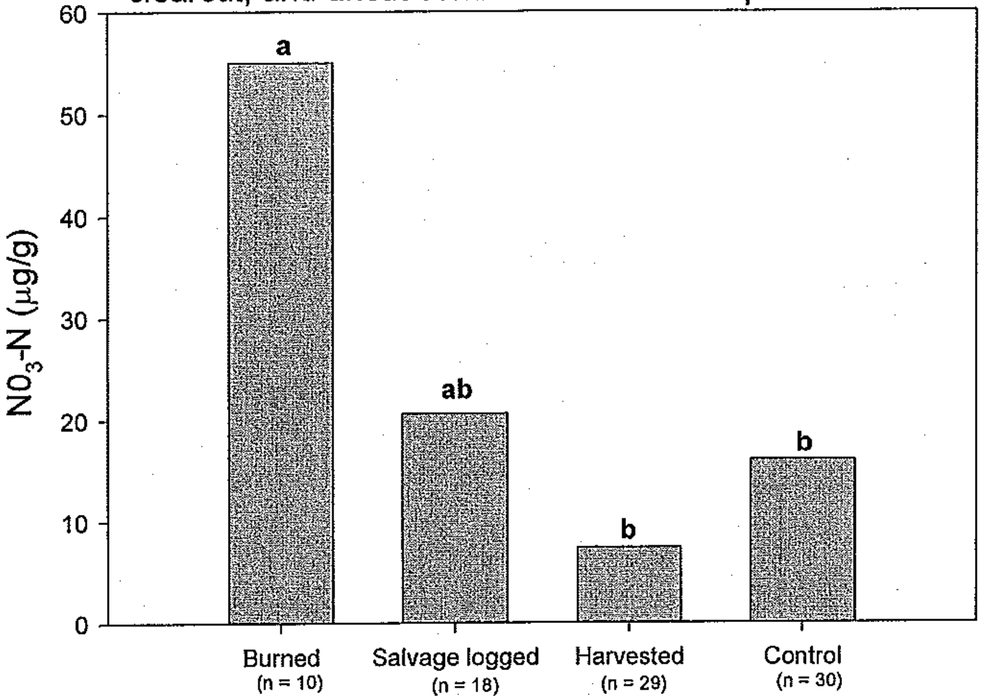
Figure 9. Forest floor extractable NH_4-N in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

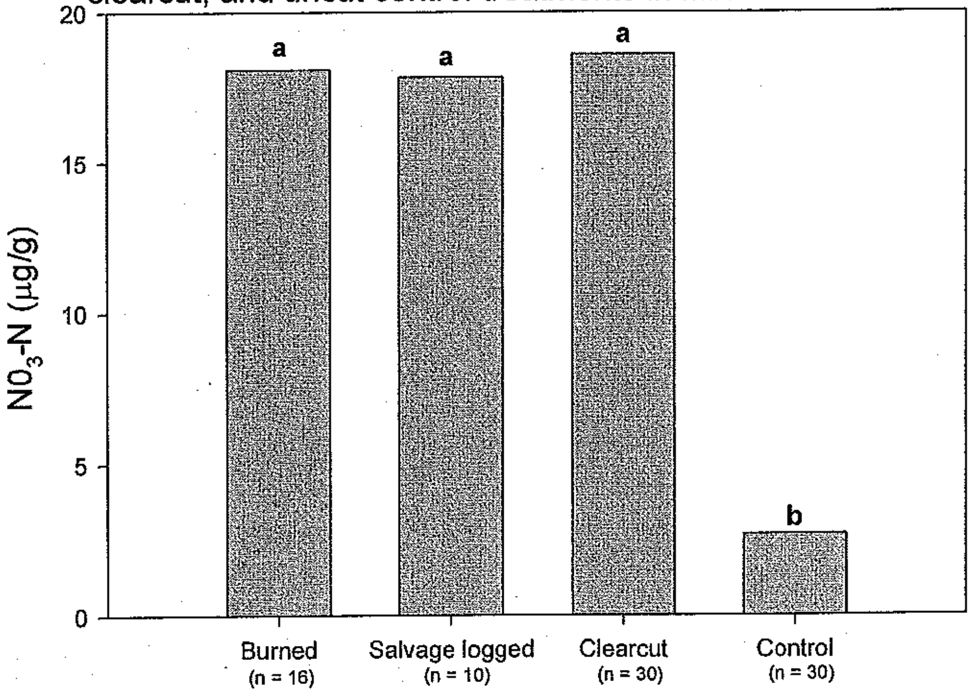
There was a treatment-stand type interaction in forest floor extractable NO_3-N concentrations, i.e., extractable NO_3-N responded differently to disturbance treatments in spruce stands than in mixedwood stands. Treatment means within each stand type are shown in Figures 10 and 11. In spruce stands, extractable NO_3-N was greatest in the burn treatment, and was significantly greater in the burn treatment than in the harvested and uncut control treatments (Fig. 10). However, in the mixedwood stands, forest floor extractable NO_3-N concentrations were similar in the burned, salvage logged, and clearcut, treatments (Fig. 11), and they were significantly greater in these disturbance treatments than in the uncut control. It appears that in the spruce stands only the burn treatment significantly increased extractable NO_3-N, while in the mixedwood stands, all disturbance types resulted in greater concentrations of extractable NO_3-N.

Figure 10. Forest floor extractable NO_3-N in burned, salvage-logged, clearcut, and uncut control treatments in spruce stands.



Different letters indicate treatment differences at α = 0.05.

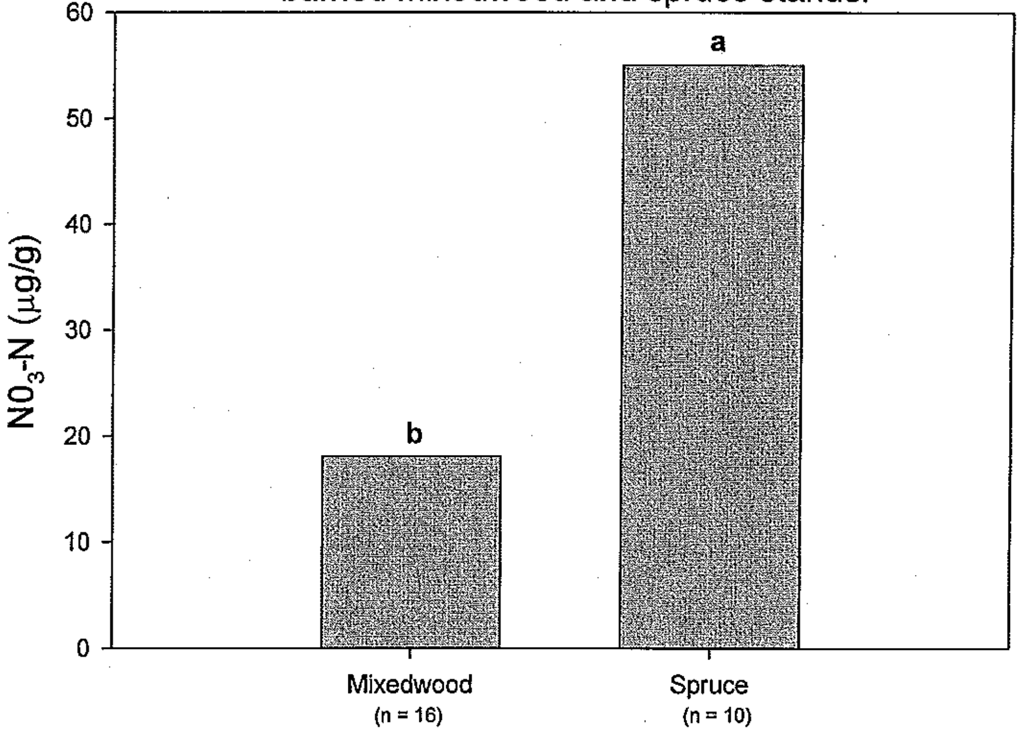
Figure 11. Forest floor extractable NO_3-N in burned, salvage-logged, clearcut, and uncut control treatments in mixedwood stands.



Different letters indicate treatment differences at α = 0.05.

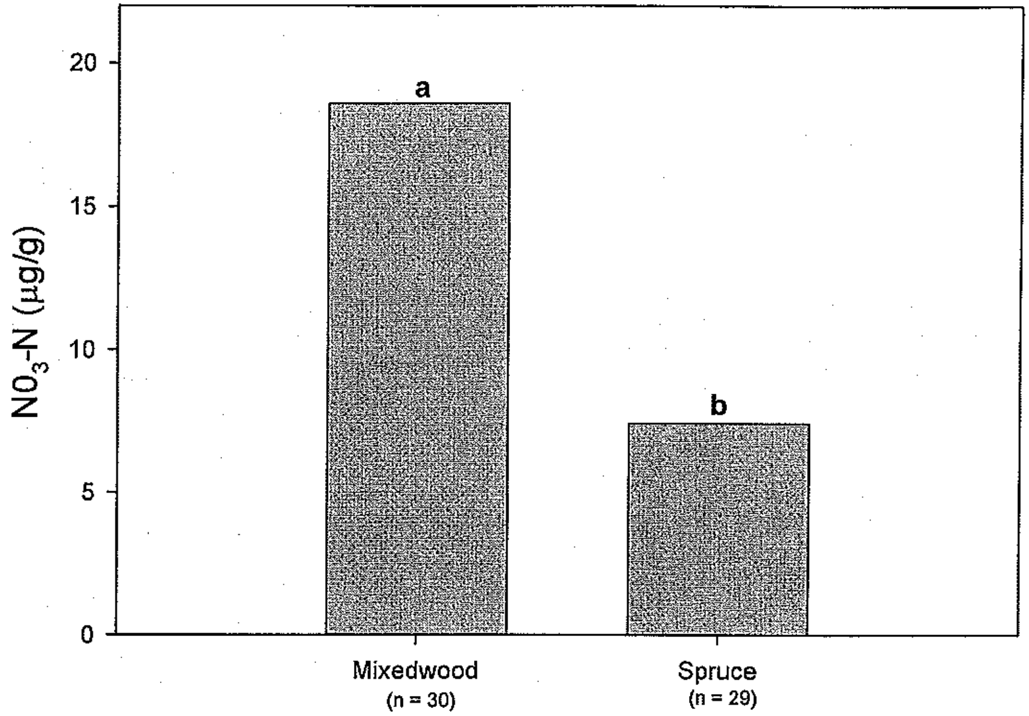
Within a disturbance treatment, response in forest floor extractable NO_3-N was different between stand types. In the uncut control stands extractable NO_3-N was significantly greater in spruce stands than in mixedwood stands (Table 1). The same pattern occurred in burned stands (Fig. 12). However, the converse occurred in harvested stands, with significantly greater extractable NO_3-N concentration in the mixedwood stands than the spruce stands (Fig. 13). There was no difference in extractable NO_3-N concentration between the spruce and mixedwood stands in the salvage-logged treatment.

Figure 12. Forest floor extractable NO_3-N in burned mixedwood and spruce stands.



Different letters indicate stand-type differences at $\alpha = 0.05$.

Figure 13. Forest floor extractable NO_3-N in harvested mixedwood and spruce stands.



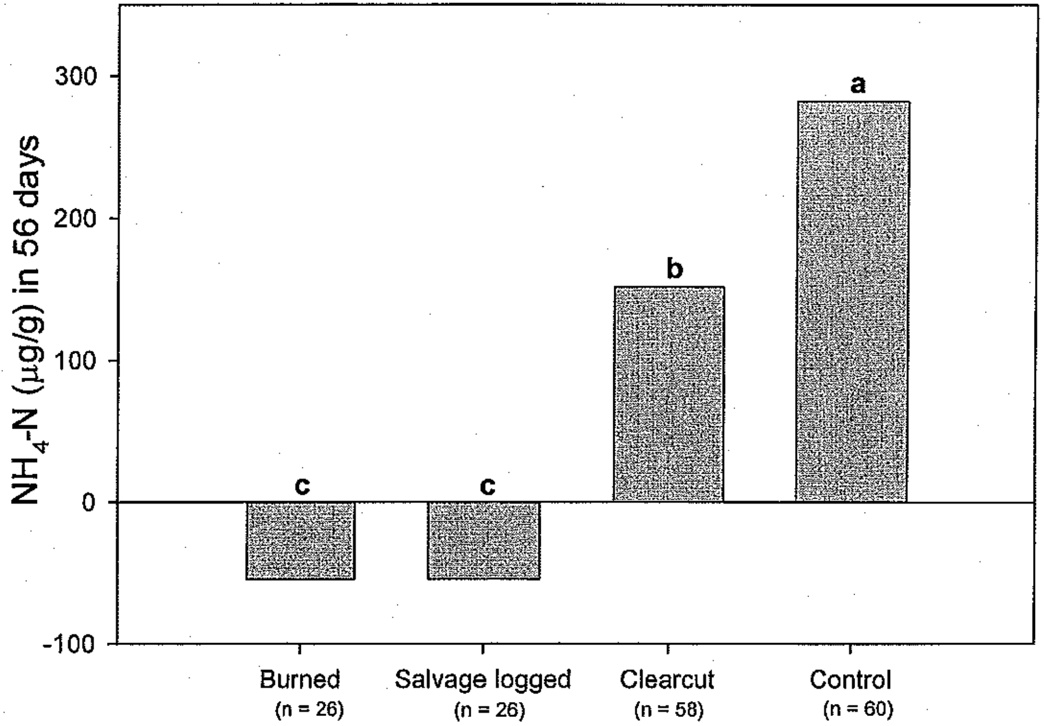
Different letters indicate stand-type differences at $\alpha = 0.05$.

Net Mineralizable NH_4-N and NO_3-N

The net NH_4-N mineralization rate was significantly greater in the uncut control treatment than in the disturbance treatments (Fig. 14). The NH_4-N mineralization rate was significantly lower in the clearcut treatment than in the control but still indicated positive net mineralization. Net immobilization (values < 0) occurred in the burn and salvage treatments, indicating nitrogen limitation of the microorganisms relative to the supply of readily decomposable carbon.

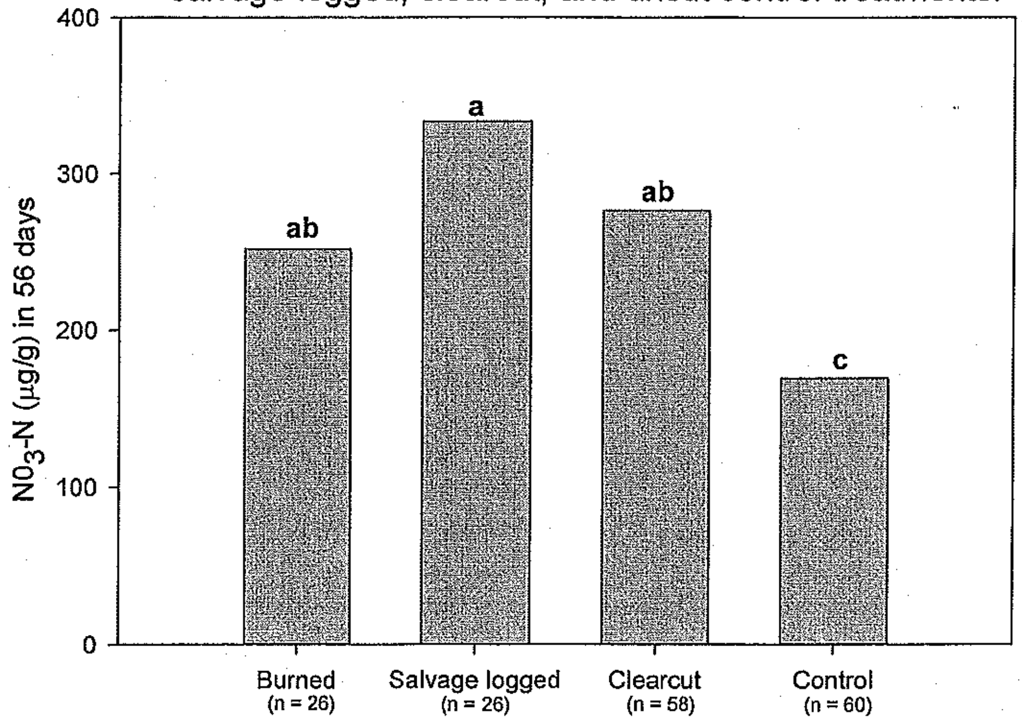
A different pattern of NO_3-N mineralization occurred. Net mineralizable NO_3-N was significantly greater in all disturbance treatments than in the uncut control, with no difference among the disturbance treatments. These results indicate that all disturbance treatments resulted in a stimulation of nitrification, regardless of the treatment (Fig. 15). All net nitrification rates

Figure 14. Forest floor net mineralizable NH_4-N in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

Figure 15. Forest floor net mineralizable NO_3-N in burned, salvage-logged, clearcut, and uncut control treatments.



were

Different letters indicate treatment differences at $\alpha = 0.05$.

positive. Differences in the patterns of net NH_4-N and NO_3-N mineralization rates suggest that these processes are to some extent occurring independently of each other and may be controlled by different factors. The relative importance of NH_4-N and NO_3-N forms to the regenerating vegetation should be followed, as this may have important implications for site productivity.

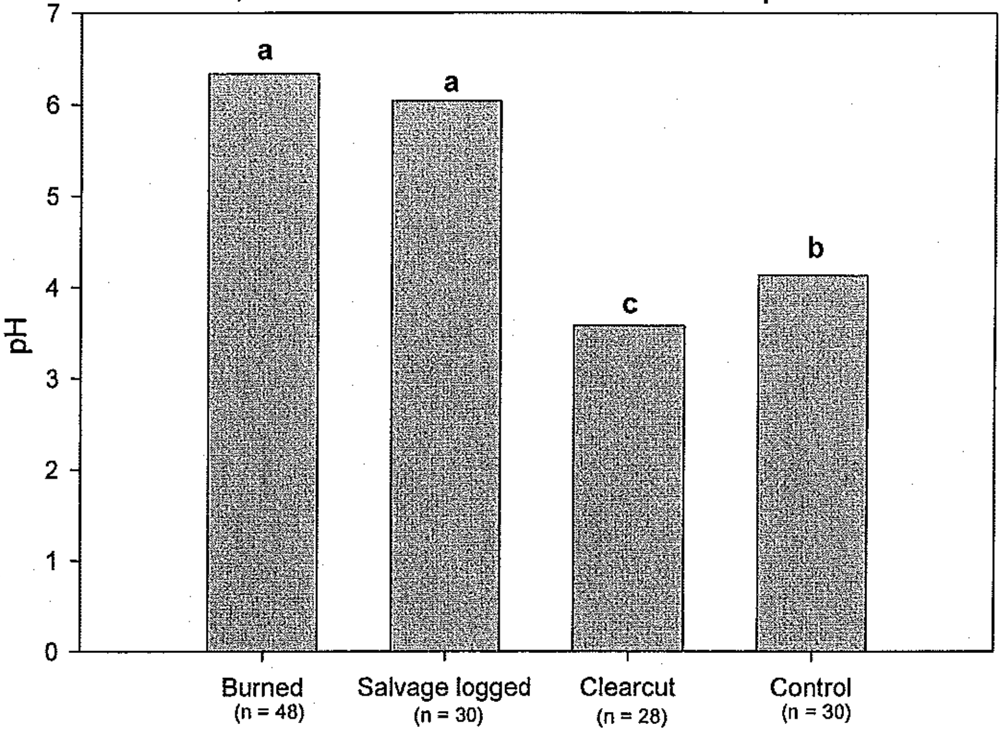
Soil NH_4-N and NO_3-N forms are soluble and readily available for plant uptake, and increased N availability following disturbance may result in increased uptake where vegetation is present. However, in the absence of actively growing plant cover, such as following the severe fire that occurred here, these soluble N forms may be readily leached and lost from the available N pool. Thus it is possible that increases in available N due to disturbance may be offset by N leaching losses from the site. Leaching losses have not been monitored in this study to date.

Surface Mineral Soil Properties

Mineral Soil pH

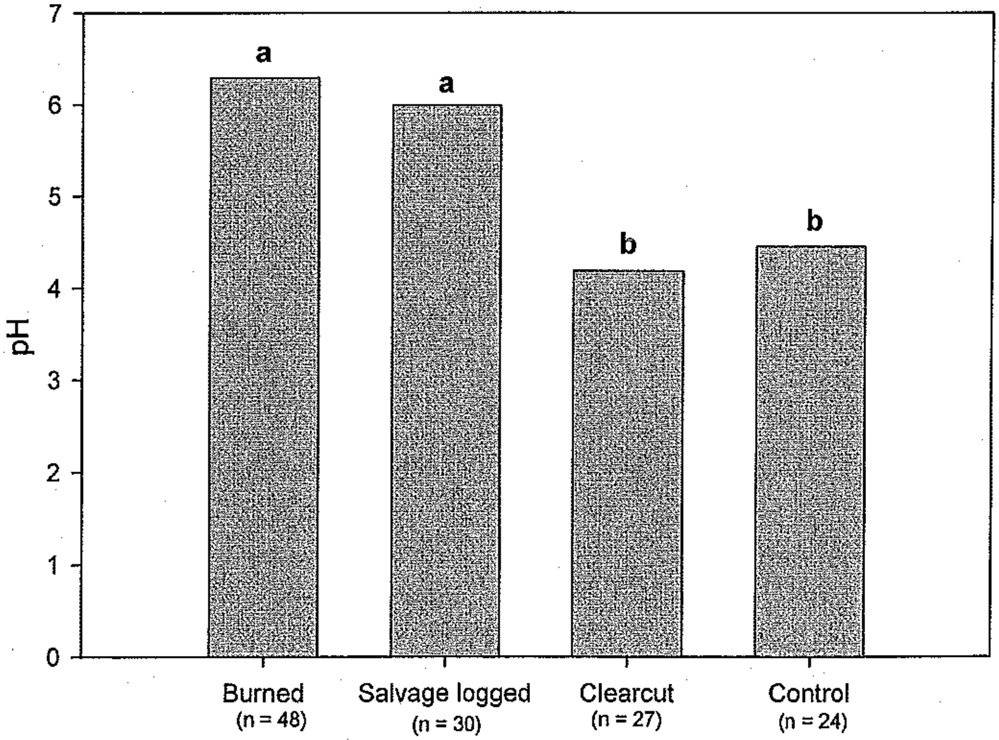
There was a significant treatment-stand type interaction for mineral soil pH, and treatment means for spruce and mixedwood stands are shown Figure 16 and 17, respectively. In both stand types pH was significantly greater in the burn and salvage-logged treatments than in the uncut control. In the spruce stands, pH was significantly lower in the clearcut treatment than in the uncut control (Fig. 16), while in the mixedwood stands pH was similar between the clearcut and the uncut control (Fig. 17). There was no difference in pH between the burn and salvage-logged treatment in either stand type.

Figure 16. Mineral soil pH in burned, salvage-logged, clearcut, and uncut control treatments in spruce stands.



Different letters indicate treatment differences at α = 0.05.

Figure 17. Mineral soil pH in burned, salvage-logged, clearcut, and uncut control treatments in mixedwood stands.

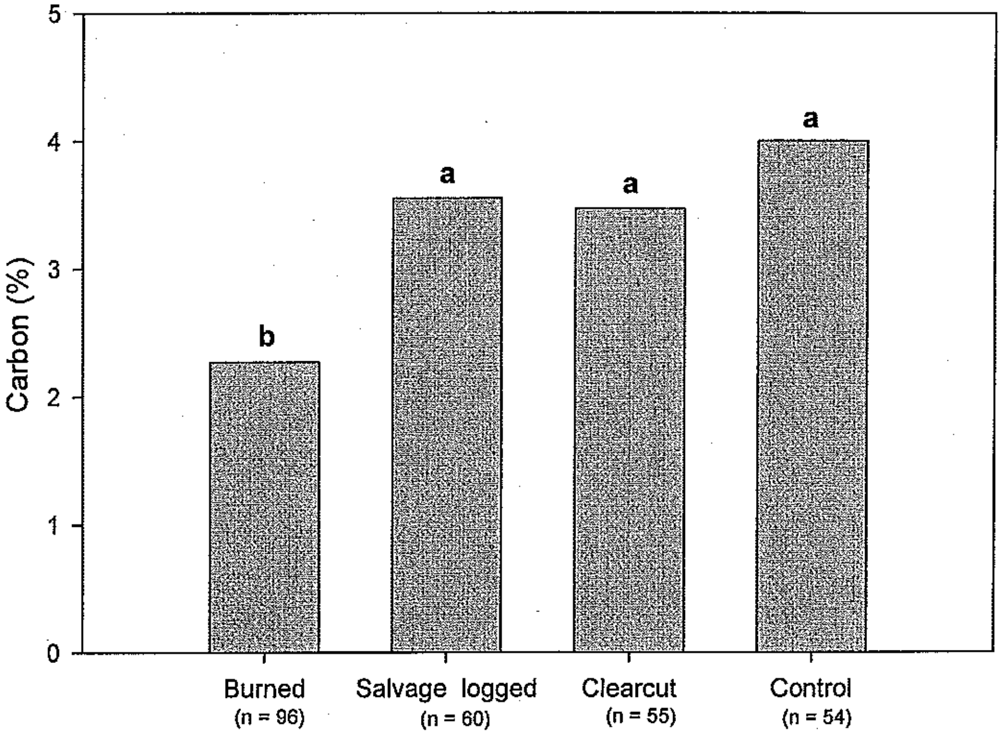


Different letters indicate treatment differences at α = 0.05.

Mineral Soil Carbon

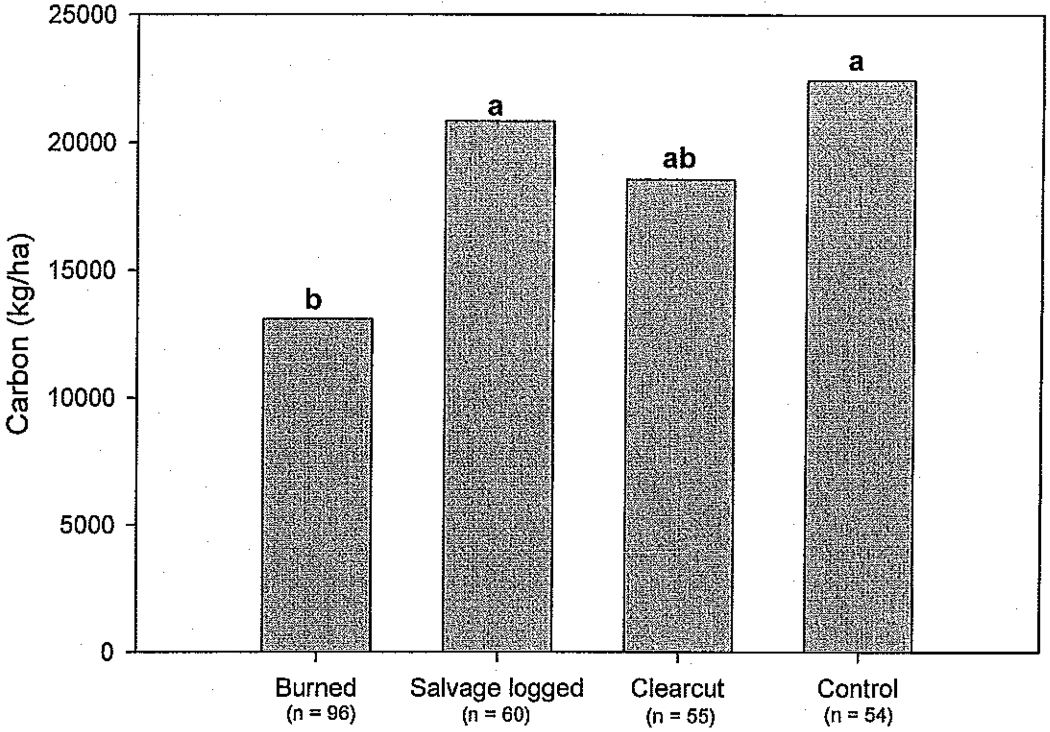
Mineral soil carbon concentration was similar in the control, clearcut, and salvage-logged treatments but was significantly lower in the burn treatment than in the three other treatments (Fig. 18). A similar trend was observed in mineral soil carbon content (kilograms per hectare) (Fig. 19), with no significant difference between the clearcut and burn treatment.

Figure 18. Mineral soil carbon concentration in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

Figure 19. Mineral soil carbon content in burned, salvage-logged, clearcut, and uncut control treatments.

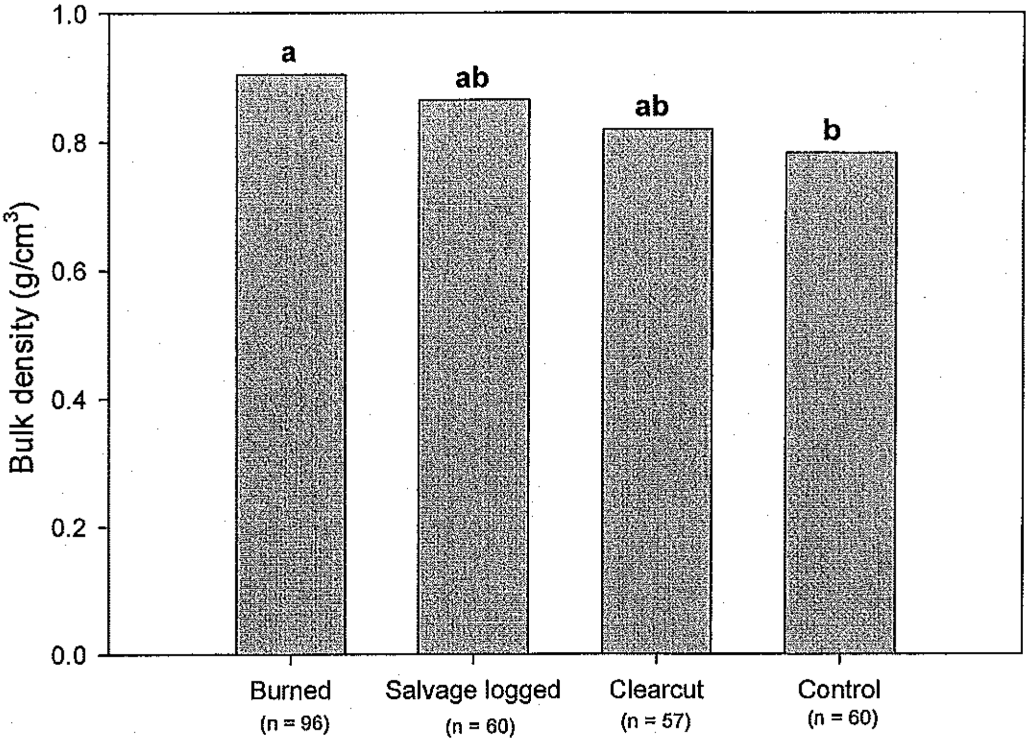


Different letters indicate treatment differences at $\alpha = 0.05$.

Mineral Soil Bulk Density

Mineral soil bulk density was least in the control, and increased progressively through the clearcut, salvage-logged, and burned treatments with bulk densities significantly greater in the burned treatment than in the uncut control (Fig. 20). The greater values in the clearcut and salvage treatments than in the control may be due to machine traffic during harvesting; however, it is not clear why the greatest values occurred in the burn treatment where there was no machine traffic.

Figure 20. Mineral soil bulk density in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

Mineral Soil Extractable and Mineralizable Nitrogen

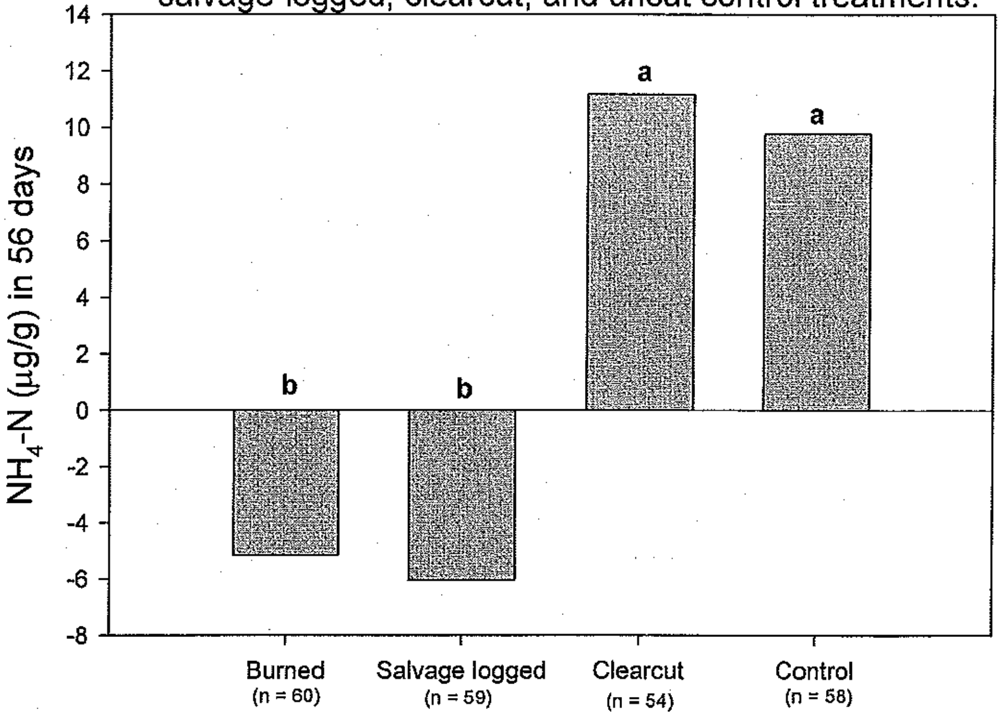
Extractable NH_4-N and NO_3-N

There were no treatment or stand type differences in extractable NH_4-N or NO_3-N in surface mineral soil.

Net Mineralizable NH_4-N and NO_3-N

Ammonium-N was mineralized in surface mineral soil in the control and clearcut treatments, and immobilized in the burn and salvage treatments (Fig. 21), similar to what occurred in the forest floor. Net mineralizable NH_4-N did not differ between the control and clearcut treatments in surface mineral soil.

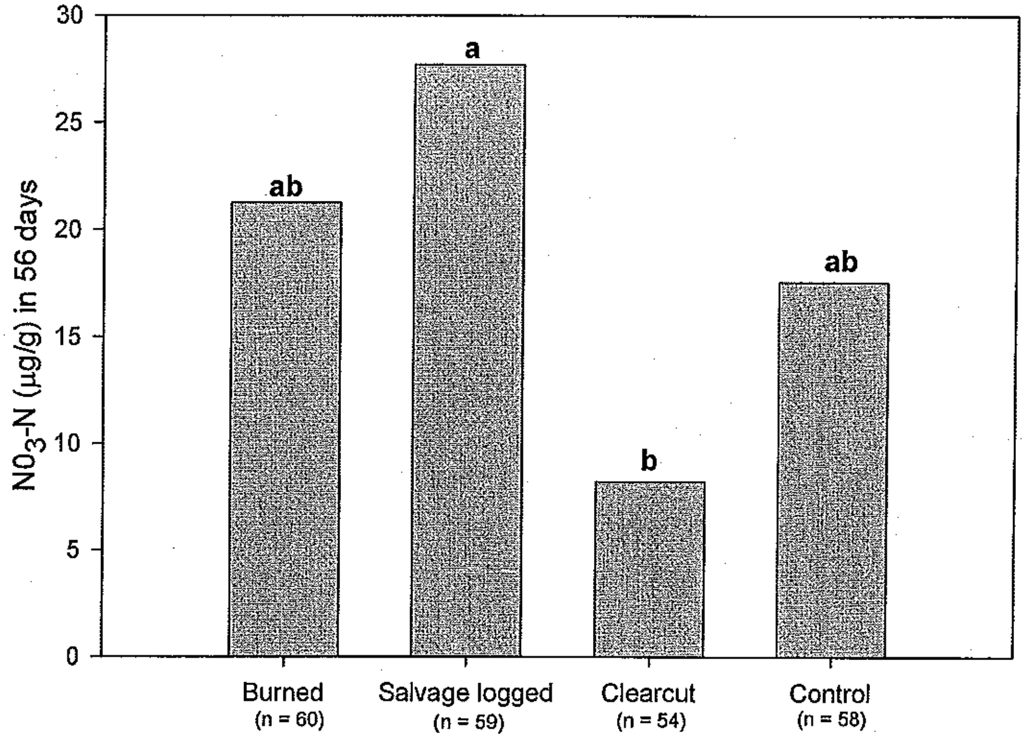
Figure 21. Mineral soil net mineralizable NH_4-N in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

Effects of disturbance treatments on net mineralizable NO_3-N were less clear in surface mineral soil than in the forest floor (Fig. 22). Net mineralizable NO_3-N was significantly lower on the clearcut treatment than in the salvage-logged treatment; however, no other differences were significant.

Figure 22. Mineral soil net mineralizable NO_3-N in burned, salvage-logged, clearcut, and uncut control treatments.



Different letters indicate treatment differences at $\alpha = 0.05$.

SUMMARY

Results to date indicate the following:

In Undisturbed Stands

- Forest floor properties such as forest floor depth, carbon concentration and content, and extractable inorganic nitrogen differed ***between undisturbed mixedwood and spruce*** stands in this region.
- Forest floor and mineral soil pH did not differ between the two stand types under undisturbed conditions.
- Differences in mineral soil properties between undisturbed mixedwood and spruce stands were limited to extractable NH_4-N and mineralizable NO_3-N .

Under Disturbance Treatments

Forest Floor

- ***Forest floor responses to burning relative to undisturbed conditions*** across both stand types were reduced forest floor depth, increased pH, decreased carbon concentration, increased extractable NH_4-N, a shift from net NH_4-N mineralization to net NH_4-N immobilization, and increased net mineralizable NO_3-N.
- ***Forest floor responses to clearcut harvesting relative to undisturbed conditions*** across both stand types were reduced pH, increased carbon concentration, increased extractable NH_4-N, decreased net mineralizable NH_4-N, and increased net mineralizable NO_3-N in the clearcut treatment.

- ***Differences in forest floor properties between burned and clearcut*** treatments across both stand types were reduced forest floor depth, increased pH, decreased carbon concentration, and a shift to net NH_4-N immobilization in the burned treatment.
- ***Differences in forest floor properties between burned and salvage-logged*** treatments were limited to lower pH in the salvage-logged treatment than in the burned treatment.
- ***Differences in forest floor properties between mixedwood and spruce*** stands across all disturbance treatments were evident in greater forest floor depth and carbon content.
- ***Interactions between treatment and stand type*** occurred in extractable NO_3-N.
    - Response of extractable NO_3-N to disturbance differed between stand types.
    - Stand-type differences in extractable NO_3-N differed among treatments.

<u>Mineral Soil</u>

- ***Mineral soil responses to burning relative to undisturbed conditions*** across both stand types were decreased carbon concentration and content, increased bulk density, and a shift from net NH_4-N mineralization to net NH_4-N immobilization.
- There were no differences in mineral soil properties ***between clearcut harvesting and undisturbed conditions***.

- ***Differences in mineral soil properties between burned and clearcut*** treatments across both stand types were decreased carbon concentration and a shift from net NH_4-N mineralization to net NH_4-N immobilization in the burned treatment.
- ***Differences in mineral soil properties between burn and salvage-logged*** treatments across both stand types were lower soil carbon concentration and content in the burned treatment.
- ***Interactions between treatment and stand type*** occurred in mineral soil pH.
    - Response of pH to disturbance treatments differed between stand types.

CONCLUSIONS

These preliminary results indicate that within the first year following disturbance by burning, salvage logging, and clearcut harvesting there were significant changes in forest floor and mineral soil properties in spruce and mixedwood stands, both relative to undisturbed conditions, and among disturbance types. Changes in pH, carbon, and forest floor depth after burning are not unexpected given the readily observable changes on the sites following the fire, and our current understanding of short-term fire effects on forest soils. Differences in forest floor properties occurred between undisturbed conditions and burning, between undisturbed conditions and clearcut harvesting, and between clearcut harvesting and burning. Differences in soil properties available for analysis to date between burning and salvage logging treatments were limited.

There were significant differences in extractable and mineralizable NH_4-N and NO_3-N among the different disturbance types on these sites. Of particular interest was the shift from net NH_4-N mineralization to net NH_4-N immobilization in both forest floor and mineral soil in the burned and salvage-logged treatments. This provides documented evidence of differences in N availability in response to different disturbance types in these forests. Different responses in available N and their interactions with stand type may have implications for nutrient cycling, the productivity and successional relationships of regenerating vegetation, and long-term site productivity under the disturbances being investigated here. Relationships between soil organic matter and nitrogen turnover are of particular importance, and these results provide a basis for further investigation of detailed nutrient cycling and organic matter processes under these disturbance types. Soil properties should be monitored over the longer term to determine their duration and their influence on other soil processes. The complete suite of nutrient analyses from these soils will also further our ability to interpret the effects of disturbance and its role in productivity on these sites.

These results also indicate that there are inherent differences in forest floor properties between the mixedwood and spruce stand types. This may result in interactions between the stand type and the disturbance type occurring in these stands, such that the effect of a disturbance on soil properties may be different in stands of differing composition. This has important implications for the management of mixedwood stands and the future productivity of mixedwood and coniferous stands on these sites.

The effects of disturbance treatments on coarse and fine woody debris quantities and rates of decomposition, and relationships among woody debris, saproxylic beetles and bryophyte communities, and nutrient turnover are currently under investigation in several auxiliary studies.

ADDITIONAL WORK 2002-2003

- Establishment of fine woody debris decomposition study with a replicated study of decomposition rates and nutrient turnover in fine woody debris at all sites was established 2002
- Analysis of soil samples from decomposition of coarse woody debris study established 2002 (T. Cobb) is underway

FUTURE WORK 2003-2004

- Completion of soil nutrient data analysis (2003-2004)
- Foliar sampling of natural regeneration and initiation of nutrient analysis (summer 2003)
- Determination of fine woody debris decomposition rates and changes in nutrient status of fine woody debris (fall 2003)
- Establishment of field mesocosm study to determine effects of saproxylic beetle and bryophyte communities on decomposition rates and nutrient turnover in fine woody debris (summer 2003)

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Appendix 1. Greenhouse Incubation Procedure

1. Determine dry mass equivalency (DME)

Take 5g (0.01g accuracy) of fresh mineral soil or fresh forest floor. Place mineral soil in drying oven at 105°C for 24 hr. Place forest floor in drying oven at 70°C for 48 hr. Weigh and record mass of dry sample X_1.

Equation (1) for dry mass equivalency (DME):

Mineral Soil
DME (X_2) = 60g x 5g/dry weight (X_1)

Forest Floor
DME (X_2) = 20g x 5g/dry weight (X_1)

2. Determine Moisture Content at Field Capacity

Place sample retention rings on pressure plate and uniformly fill with mineral soil or forest floor material. Saturate the samples and plates with distilled water for 24 hr. Apply 33 kPa (1/3 bar or 5 psi) of pressure to the plate for 24 hr. Soil is then at field capacity. Weigh and record mass of sample at field capacity.

Take the sample at field capacity from step 2 and oven dry. Place mineral soil in drying oven at 105°C for 24 hr. Place forest floor sample in drying oven at 70°C for 48 hr. Weigh and record mass of oven dry sample.

Equation (2) for moisture content at field capacity (FC):

Mineral Soil
Moisture content % H_20 = wet mass (from FC) - dry mass (from FC) / wet mass (from FC).

80% H_20 = 0.8 (% H_2O)
80% FC_{equiv} = 60/ (1-80% H_20)

Forest Floor
Moisture content % H_20 = wet mass (from FC) - dry mass (from FC) / wet mass (from FC).

FC_{equiv} = 20/ (1-% H_20)

3. Determine amount of water to be added to reach FC from fresh sample.

Weigh the dry mass equivalency for 60 g mineral soil or 20 g forest floor sample. Place in 500 ml plastic tub. Add volume of distilled water calculated in equation below to bring sample to field capacity or 80% field capacity.

Note: if Equation (3) is ≤ 0 then do not add water. If ≤ 0, add DME to plastic tub.

Equation (3) for amount of water required to bring sample to field capacity:

Mineral Soil
80% $FC_{equiv} - DME$ = mass of water to be added

Forest Floor
$FC_{equiv} - DME$ = mass of water to be added

Each tub was placed into a plastic bag and twisted shut. Tubs were placed in the greenhouse for 56 days. Shade cloth was installed to cover the entire bench, filtering approximately 99% of available light. Temperature for the duration of the incubation was set at 25°C. Moisture content for the duration of the incubation was monitored bi-weekly on a mass basis. Water was added to bring each sample up to mass at field capacity.

4. Additional subsamples were extracted in 2M KCl prior to the incubation to determine intial NH_4-N and NO_3-N values. The incubated samples were extracted in 2M KCl following the incubation. Net mineralizable N is determined as the difference between the final (post-incubation) and initial (pre-incubation) values. This represents what was mineralized over the course of the incubation, less what was microbially immobilized within the sample over the length of the incubation.

Appendix 2: Data Transformations

Parameter	Transformation
Mineral soil carbon concentration	reciprocal
Forest floor depth	square root
Forest floor mass	log
Forest floor pH	square
Mineral soil pH	logrithmic
Forest floor bulk density	logrithmic
Mineral soil bulk density	square