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Extension Note

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The Soil Ecosystem of an ESSF Forest and its Response to a Range of Harvesting Disturbances

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Abstract

This extension note describes some of the effects of timber harvesting on the soils at the Sicamous Creek Silvicultural Systems Project study site for the 5-year period since harvesting. The study site is located in the ESSF zone near Sicamous, B.C. Five harvesting treatments were applied: no harvesting, single-tree selection, 0.1-, 1-, and 10-ha clearcuts. A variety of studies investigated the effects of opening size and distance from the edge of the cut area on soil nitrogen dynamics, nutrient cycling, soil food webs, ectomycorrhizae, and fine roots. Generalizations regarding short-term effects on the below-ground organisms and processes are difficult. A complete absence of sporocarp fruiting, increased rates of nitrogen mineralization and increased nutrient leaching losses were noted in the first growing season after harvest. Decreased ectomycorrhizal diversity and fine-root biomass were measured after one growing season. Shifts in community structure occurred for micro-arthropods and bacteria while no discernible impact was detected for decomposition rates and total collembola numbers. All these changes persisted for up to 5 years after treatment, although nutrient leaching peaked after 3 years. The major influence of the forest edge into the opening occurred within approximately one-half of the tree canopy height of the uncut forest. Cutting practices that create a range of opening sizes would best maintain the widest variety of soil biological diversity and functions.

Introduction

Little information is available on many aspects of the ecology of high-elevation Engelmann Spruce–Subalpine Fir (ESSF) forests, and even less on below-ground organisms and processes in these ecosystems. To better understand the ecology of these forests and their response to timber harvesting, the Sicamous Creek Silvicultural Systems Project was initiated in the southern Interior of British Columbia. The specific objectives of the soil ecology component of this project were to gain an understanding of the properties and processes affecting soil productivity and the effects of harvesting disturbance on those processes. Information gained from these studies will enable these high-elevation forests to be managed in a manner that sustains both soil and forest productivity.

The activities of soil-dwelling organisms are directly related to site

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productivity. For example, bacteria and decomposer fungi produce the enzymes necessary to decompose organic matter and release inorganic forms of nutrients. Nematodes and micro-arthropods feed on bacteria and fungi and release excess mineralized nitrogen into the soil solution. Ectomycorrhizal fungi take up these nutrients and transfer them to their plant hosts. Many of these organisms have never been investigated in ESSF forests and, therefore, even baseline information documenting species presence is lacking.

This extension note summarizes the first 5 years of results pertaining to the effects of timber harvesting on the soils at the Sicamous Creek study site.

Study Site

The Sicamous Creek Silvicultural Systems Project is situated in the Hunter Range, southeast of the town of Sicamous in the southern Interior of British Columbia. The study site is located in the ESSF wet cold (ESSFwc2) biogeoclimatic variant, and ranges in elevation from 1500 to 1850 m.

The dominant tree species are subalpine fir (*Abies lasiocarpa*) and Engelmann spruce (*Picea engelmannii*); these species range in age from 95–325 years. Subalpine fir constitutes 82% of the canopy species. The site series on zonal sites is the subalpine fir–azalea–oak fern unit (Lloyd et al. 1990). Soils on mesic sites are classified as Orthic Humo-Ferric Podzols with hygric areas classified as Gleyed Sombric Brunisols and Orthic Gleysols. Forest floors range in thickness from 1 to 14 cm and contain approximately 10–30% decayed wood. Humus forms are predominantly Hemimors.

Treatments

The site was divided into three elevation blocks, and five main treatments were applied to each block: no harvesting, single-tree selection, 0.1-, 1-, and 10-ha clearcuts (Figure 1). Each treatment unit is approximately 30 ha in size. The site was harvested during the winter of 1994–95. Approximately 33% of the total timber volume was

FIGURE 1 *Sicamous Creek study site viewed from the NE (photo by Alan Vyse).*

TABLE 1 *Summary of soil ecology studies at Sicamous Creek*

Study	Sampling method	Sampling locations	Parameters measured	Reference
Soil chemistry and nitrogen dynamics	Soil collection, field incubation of soil and litter bags	Plots in all treatments; transects in one 10-ha block	Soil chemistry, N mineralization; litter decomposition	Hope and Prescott 2000
Fine roots	Soil cores	Plots in control, 0.1-, and 1.0-treatments; transects in one 10-ha block	Fine root biomass and nutrient content; fine root decomposition	Welke and Hunt 1999
Ectomycorrhizae	Soil cores, bioassay seedlings, nursery seedlings	Plots in control, 0.1-, 1.0-, and 10-ha treatments, plus transects in the three 10 ha- and in three 1.0-ha openings.	Ectomycorrhizal diversity and community structure	Hagerman et al. 1999a, 1999b, Jones et al. 2000
Hypogeous Sporocarps	Collection of below-ground sporocarps in 4 m^2 plots	Control, 0.1-, 1.0-, and 10-ha treatments	Biomass	Jones et al. 2000
Soil food-webs	Soil collection from circular plots 10 m in diameter	Control, 1.0-, and 10-ha treatments	Total soil bacteria, fungi and nematodes; N mineralization and denitrification	Hope and Johnson 1999
Soil micro-arthropods	Soil cores	Centre of control, 0.1-, 1.0- and 10-ha treatments, plus transect in one 10-ha block	Mites and collembola; abundance and diversity	Nadel 1999
Nutrient dynamics	Analysis of soil water samples and plants	Control, 10-ha treatments, plus selection cut for N-fixation	Nutrient inputs and outputs in solution, N-fixation	Feller 1999

removed in each of the four treatments. All timber harvesting treatment areas were site prepared by a combination of mounding and screefing. Most soil ecology studies took place in undisturbed ground within the site-prepared areas.

Sampling

Sampling techniques were specific to the property or process being measured, and details can be found by referring to the original studies (Table 1). Most studies investigated the effect of opening size and distance from the edge of the cut area.

Soil Ecology of the Undisturbed Forest

Chemistry

The soils at the Sicamous site exhibit the characteristic acidic pH found in other ESSF soils. The amounts of nitrogen and sulphur were lower in the forest floor than in the surface mineral soil because the forest floor at Sicamous is relatively thin (Table 2). However, the total nutrient capital of these elements, together with the content of available phosphorus and cations (data not shown) and the carbon to nitrogen (C:N) ratio

TABLE 2 *Chemical properties of the undisturbed forest soil at Sicamous Creek*

	Soil chemical property					
Sample	**Total C**	**Total N**	**Total S**	**C:N**	**Mineralizable N**	**pH**
Concentration (g/kg)						
Forest floor	432	15.1	1.5	28.7	5.8	4.3
Mineral soil	48.0	2.4	0.2	19.8	0.5	3.9
Content (kg/ha)						
Forest floor	16455	610	62		23	
Mineral soil	55665	2520	259		50	

of both forest floor and mineral soil, indicate that these soils are as fertile as those from lower-elevation sites in the Kamloops Forest Region. Mineralizable nitrogen and C:N ratio indicate that the forest floor had greater microbial nitrogen (the most available N) and higher rates of nitrogen turnover on a per gram basis than did the mineral soil. Nitrate comprised 1–10% (depending on the season) of the extractable nitrogen pool in forest floors, and between 7–20% in the surface mineral soil.

Fine Roots and Litter Inputs

In western temperate forests, annual fine root turnover ranges from 40% to 90% of the standing crop and contributes an estimated 2–5 times more organic matter to the soil than leaf and branch litter combined (Fogel and Hunt 1979). Fine roots (< 2 mm diameter) were an important contributor to organic matter in the undisturbed forest at Sicamous Creek, with annual maximum standing crops over 5 years ranging from 657 to 5073 kg/ha. Total annual input from above-ground litterfall measured over 2 years was 3473 kg/ha. This litter fall was comprised of needles (73.4%), leaves (1.9%), fine woody debris (9.1%), and coarse woody debris (15.6%).

Ectomycorrhizal Fungi

Ectomycorrhizal fungi play a vital role in the forest soil ecosystem, forming a symbiotic association with plant roots and contributing to the soil food-web as a source of food for invertebrates and small mammals. The fruiting bodies of some of these fungi form below-ground, are called hypogeous sporocarps (or truffles), and are a common food source for small mammals. Species richness of the hypogeous sporocarps sampled from the uncut forest ranged from 1–7 species per 4 m^2 plot. While over 20 taxa were described in 6 years of study, three species—*Hydnotria variiformis, Hysterangium coriaceum,* and *Thaxterogaster pingue*—were typically the most abundant. Spatial variation in fungal biomass was marked, reflecting the highly clumped distribution of many species.

The ectomycorrhizal community in the uncut forest was represented by a diverse array of fungal species colonizing the fine roots of trees. Numerous rare types and a few dominant types characterize the community structure. Thirty-nine types were described during the 3 years of soil-core sampling.

Soil Food-Webs

Four essential components of the soil food-web were investigated: bacteria and fungi, which both decompose organic matter, and nematodes and micro-arthropods, which are the most abundant consumers of bacteria and fungi. Of these four groups, fungi were by far the largest contributors to biomass followed by bacteria, nematodes, and micro-arthropods.

Seven collembola families and 40 mite families were detected. A number of collembola species identified in this study have not previously been reported from British Columbia. These included *Ceratophysella glancer, Pratanurida tananensisg*, and *Folsomia inoculata*, as well as several species new to science. Micro-arthropod densities (104 000 mites and 64 000 collembola per square metre in the uncut forest) were comparable to those reported in other studies. The most abundant mites were the oribatid mites, which are typical of Mor humus layers. Like the collembola, these mites prefer the moist conditions that were generally found in both the openings and forest.

Nutrient Cycling

Annual inputs and outputs by solution (precipitation and mineral soil leachate, respectively) in the uncut forest were relatively low, with inputs of nitrogen, phosphorus potassium, sulphur, magnesium, and calcium each averaging less than 2 kg/ha annually and outputs averaging less than 3 kg/ha annually for all nutrients except potassium (3.2 kg/ha per year) and calcium (6 kg/ha per year). Total nitrogen inputs were closely balanced by total outputs (0.9 kg/ha per year and 1.0 kg/ha per year, respectively). This indicates that no net nitrogen input into the forests occurs via the solution pathway. Nitrogen fixation inputs measured for a chronosequence of ESSF sites (including Sicamous) from zero to greater than 200 years were relatively low (< 0.5 kg/ha per year) compared to nitrogen demands by the forest vegetation.

Short-term Responses to Disturbance: Opening Size

Fine Roots

Three and four years after harvest (1997 and 1998), both active and total fine root biomass were significantly higher in the uncut forest compared with the 0.1-ha and 1.0-ha openings (Figure 2). For the spring sampling in the fifth year after harvest, fine root biomass in the uncut controls was actually lower

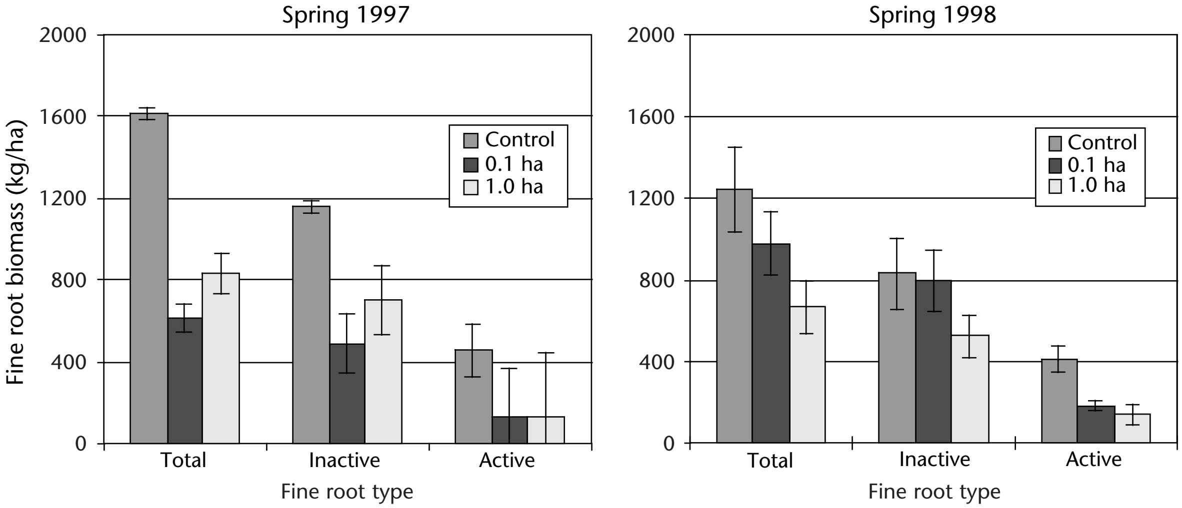

FIGURE 2 *Effects of opening size on fine root biomass during spring sampling in 1997 and 1998 (bars are standard errors of the means).*

than either of the openings, probably because of the high, late-melting snowpack in that year (data not shown).

Ectomycorrhizal Fungi

Logging had a dramatic effect on the incidence of below ground ectomycorrhizal sporocarps. Throughout the 5 years of post-harvest sampling, no sporocarps were found in any of the openings (0.1 ha, 1.0 ha, and 10 ha). For ectomycorrhizal roots, no differences existed in diversity (expressed as number of ectomycorrhizal types) during the first growing season after harvesting. In subsequent years however, harvesting had a significant negative effect. The persistence of fine roots and ectomycorrhizal diversity declined significantly in the openings away from the forest edge (Figure 3). This same pattern of decline was observed for the diversity of fungi colonizing non-mycorrhizal field bioassay seedlings (Figure 4).

Nursery-grown seedlings planted in the openings did not exhibit the pattern of reduced inoculum levels, which was detected in the non-mycorrhizal seedlings. This nursery stock was extensively colonized by mycorrhizal fungi before planting, and these fungi evidently were effective competitors for new colonization sites along extending roots in the field. Because of this, the overall diversity of ectomycorrhizae on the nursery-grown seedlings was lower than on the young non-mycorrhizal seedlings.

Food Webs

With the exception of bacteria, all components of the soil food-web showed a harvest-related shift, 2–4 years after harvest (Table 3). Particularly evident was the decline in fungal

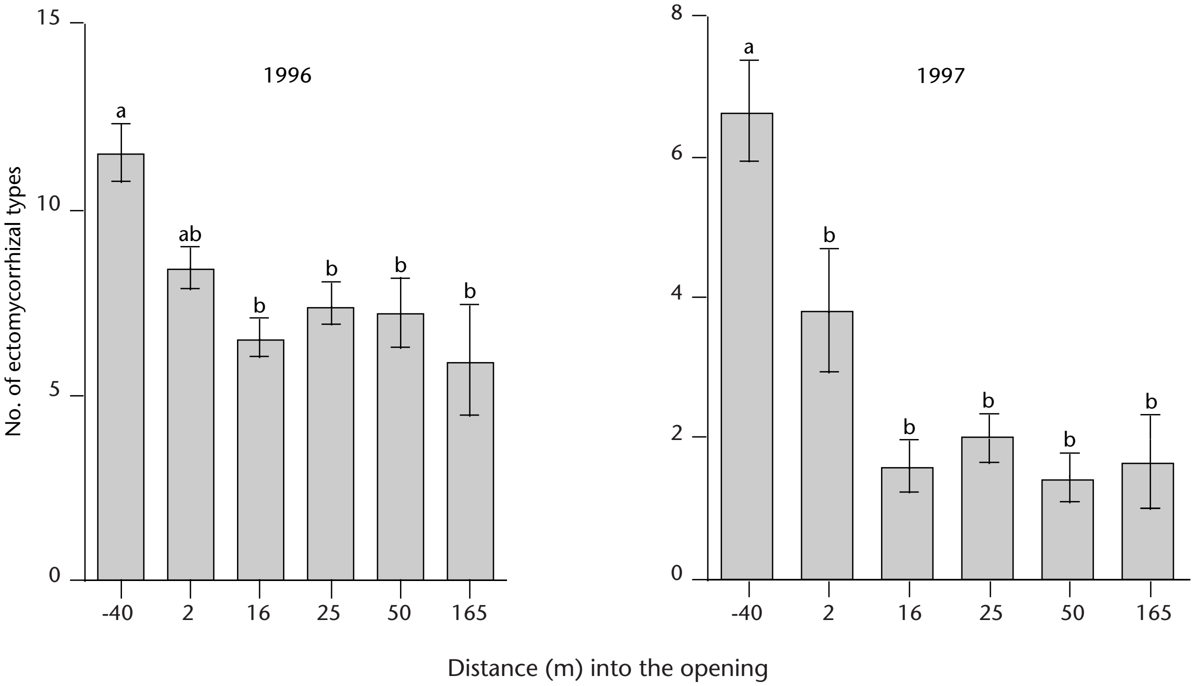

FIGURE 3 *Richness of ectomycorrhizae with increasing distance from the block edge (with negative values representing distance into the forest), in soil cores sampled two and three growing seasons after logging. Values with same letter are not significantly different at P<0.05. Error bars represent one standard error of the mean.*

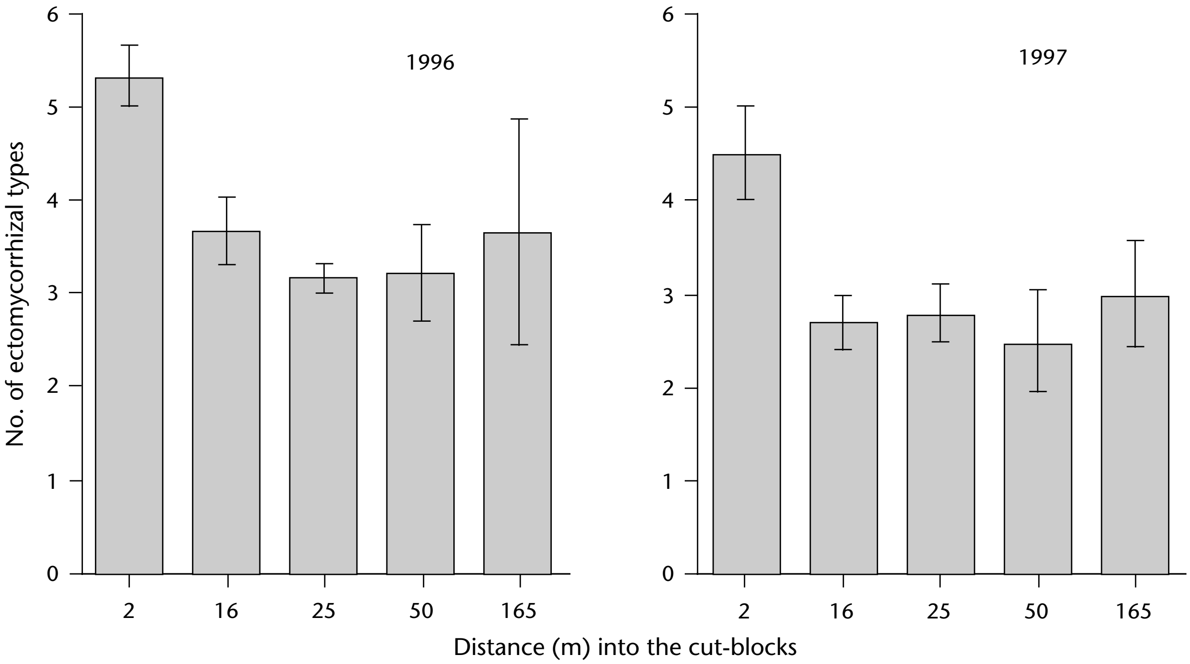

FIGURE 4 *Number of types of ectomycorrhizae encountered on seedling roots grown at Sicamous Creek for 13 weeks, two and three growing seasons after logging, with increasing distance from the block edge. Error bars represent one standard error of the mean.*

TABLE 3 *Biomass for the food-web variables measured at Sicamous Creek two through four years following logging at plots located in the undisturbed forest, and the centre of the 1.0- and 10-ha openings*

Food-web variable	Year	Forest	1-ha centre	10-ha centre
Bacteria (mg/g dry soil)	1996	63.40 a	64.30 a	67.34 a
	1997	199.06 a	286.37 a	242.03 a
	1998	256.94 a	404.17 a	493.12 a
Fungi (active + inactive) (mg/g dry soil)	1996	3972.67 a	2866.21 a	3012.67 a
	1997	2803.48 a	1916.41 b	2018.94 a
	1998	2098.51 a	638.84 bc	1108.38 b
Nematodes (per g dry soil)	1996	15.59 a	30.26 a	15.26 a
	1997	16.16 a	14.23 a	11.00 a
	1998	67.99 a	24.7 b	20.57 b
Micro-arthropods (per g dry soil)	1996	6.23 a		1.66 b
	1998	8.78 a	4.06 b	4.36 b

Within rows values followed by different letters are significantly different at $p < 0.15$.

biomass (active + inactive) in forest floor samples from the openings. An increase in bacterial and fungal biomass is often observed after harvest because of the warmer soils and increased moisture. The results from Sicamous Creek do not support this model; in fact, fungal biomass was reduced and bacterial biomass remained unchanged. Although the overall numbers of bacteria were unchanged, a community shift was detected, with denitrifying bacteria more common in the openings.

The effect of harvesting on micro-arthropod densities varied depending on the sampling method and the time of year. Biomass estimates generated from the food-web study revealed a decline in these fauna in the 10-ha openings relative to the uncut forest. In the finer-scale soil fauna study, no effect of harvesting (any opening size) on micro-arthropod numbers was detected in forest floor samples. This discrepancy may be related to the timing of sampling. The food-web sampling was undertaken in the late summer when soil conditions were warmer and drier than in the late fall when the soil faunal samples were collected.

Although canopy removal had no clear influence on micro-arthropod numbers during the first 2 years after harvest, differences were detected in the third year. By this time, the highest numbers of mites in forest floor samples were observed in the 10-ha openings. The major effect of canopy removal was in mineral soil samples, where the number of mites in all openings (Table 4) and the abundance of two of the major families of collembola, were significantly reduced. However, total numbers of collembola were unaffected by canopy removal (all opening sizes) in both forest floor and mineral soil samples (Table 4).

Nutrient Cycling

Forest harvesting increased leaching losses of nutrients, particularly nitrogen (primarily nitrate) and potassium. Accumulated 4-year post-harvest losses attributed to leaching were 46 and 49 kg/ha, respectively. Annual nitrogen losses represent approximately 0.5% of the total nitrogen content of the forest floor and surface mineral soil (Table 2). Harvesting-induced losses of magnesium, calcium, and sulphur ranged from 10 to 20 kg/ha per 4 years, while phosphorus losses were less than 0.5 kg/ha per 4 years. Leaching losses peaked between the second and third year after harvest, and declined substantially in the fourth year (Table 5).

Nitrogen Dynamics

The concentrations of mineral nitrogen (ammonium and nitrate) measured in incubated soil samples (forest floor + mineral soil) were significantly greater in the 0.1-, 1.0-, and 10-ha openings than in the control and selection cut in the 4 years of study ending in 1999. This indicates that nitrogen mineralization

TABLE 4 *Mean density of soil mites and collembola (individuals/m^2) collected from the forest floor and mineral soil at the end of three growing seasons after harvest (1997)*

	Uncut control	**0.1 ha**	**1.0 ha**	**10.0 ha**
Forest floor				
Total	169 390 a	126 120 a	129 160 a	174 440 a
Mites	105 410 ab	70 790 b	75 820 ab	116 910 a
Collembola	63 980 a	55 330 a	53 340 a	57 530 a
Mineral Soil				
Total	101 430 a	53 060 b	35 310 b	49 900 b
Mites	72 300 a	33 060 b	20 330 b	33 850 b
Collembola	29 130 a	20 000 a	14 970 a	16 050 a

Means within a row followed by the same letter are not significantly different ($p < 0.05$).

TABLE 5 *Estimated annual leaching losses (kg/ha) measured in the 10-ha openings 1–4 years after harvesting*

Year	Nutrient loss (kg/ha) Total $N^{a,b}$	Organic N^{a}	Nitrate N^{a}	Ammonium N^{a}	Total P^{a}	K^{a}	Mg^{a}	Ca^{a}	SO_4–S^{a}
1994/1995	3.4	1.7	1.6	0.1	0.0	10.2	1.1	3.5	1.7
1995/1996	14.9	2.9	11.5	0.5	0.1	18.8	2.7	12.0	4.2
1996/1997	19.1	2.5	16.4	0.2	0.1	19.0	5.5	1.8	4.8
1997/1998	8.4	1.1	7.3	0.0	0.1	1.4	2.0	3.8	1.5
4-Year Total	45.8	8.2	36.8	0.8	0.3	49.4	11.3	21.1	12.2

[a] nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg), calcium (Ca), and sulphate–sulphur (SO_4–S)
[b] total N is the sum of organic, nitrate, and ammonium N

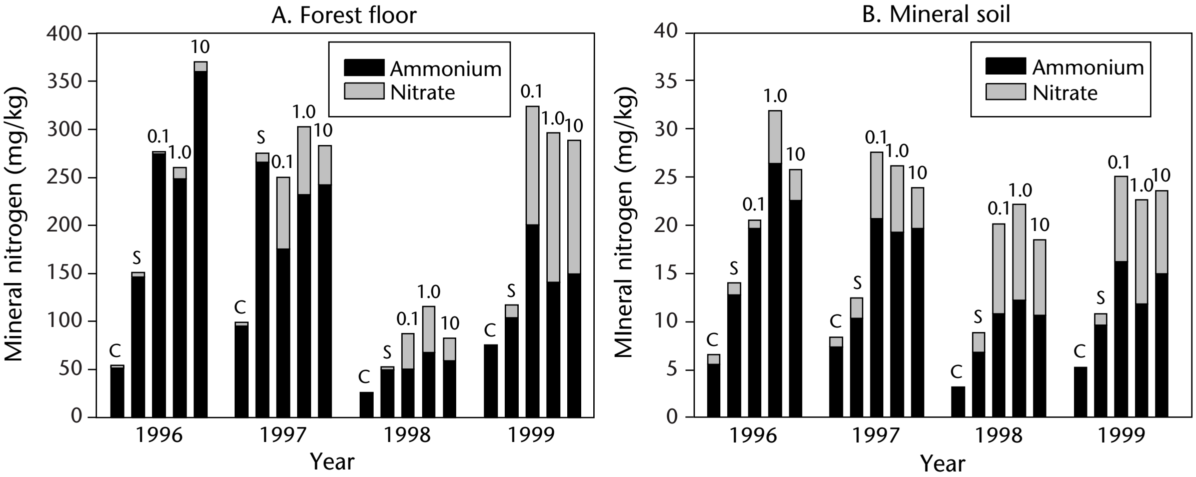

FIGURE 5 *Concentrations of ammonium-N and nitrate-N in forest floor and mineral soil samples after a 6-week field incubation from July to mid-August, over a 4-year period from 1996–1999. Treatment symbols marked on each bar are: C, control; S, selection cut; and 0.1-, 1.0-, and 10-ha openings.*

rates were higher at these locations (Figure 5). Additionally, the proportion of nitrate relative to ammonium increased over time in the larger (≥ 0.1 ha) openings.

The increased concentrations of mineral nitrogen commonly observed after clearcutting are often explained by the moister and warmer conditions in the openings, which leads to faster decomposition and mineralization, and higher concentrations of nitrate (see Prescott et al. 2000 for a full discussion of this issue). However, at Sicamous Creek, increases in nitrogen were not accompanied by faster decomposition rates. In fact, no opening size effect was observed in the decomposition rates of any of the five substrates (spruce/fir needles, spruce/fir roots, forest floor material, aspen leaves, lodgepole pine needles) over the 5-year period since harvesting.

Short-term Responses to Disturbance: Distance from the Edge

Ectomycorrhizal diversity assessed from soil cores and bioassay seedlings declined with increasing

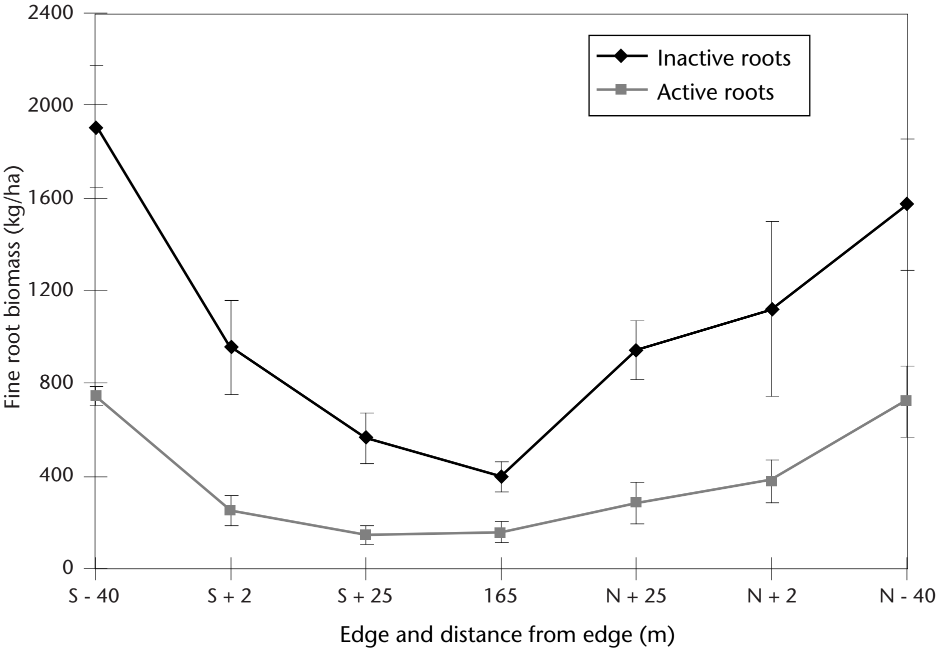

FIGURE 6 *Inactive and active fine root biomass along transects in 10-ha plots in the fall of 1997 (bars are standard errors of the mean). Negative distances from the edge represent points into the forest, positive distances represent points into the opening.*

distance from the forest edge into the openings. Diversity became significantly lower between 2 and 16 m from the forest edge (Figures 3 and 4). This was observed 2 and 3 years post-harvest and may be explained by the maintenance of active ectomycorrhizae associated with trees whose roots extend into the openings from the adjacent forest. No differences were observed in the diversity indices at corresponding distances from the edge of different opening sizes (as detected by soil cores and bioassay seedlings) 1–3 years after logging. The diversity of ectomycorrhizae associated with nursery-grown seedlings was not affected by distance from the edge. Fine root biomass also declined with distance from the edge in the 10-ha openings (Figure 6). Samples taken in the fall of 1997 and 1998 had significantly less fine root biomass (active + inactive) at the centre of the opening compared with the edges and within the forest. No differences in micro-arthropod numbers were detected with distance from the edge up to 3 years after harvest. However, significantly fewer mites were evident in samples taken from the south edge of the 10-ha opening as compared with the centre and north edge regions. There was a trend of increased nitrogen mineralization approaching the north edge of the 10-ha openings relative to the centre and south edges, 1 and 2 years after harvest.

Summary and Implications for Forest Management

- The below-ground organisms and processes measured at Sicamous Creek responded in different ways to the various treatments during the first 5 years after harvest, making generalizations difficult. Some responded immediately to harvesting (complete absence of sporocarp fruiting, increased rates of nitrogen mineralization and increased nutrient leaching losses, while others responded after one growing season (decreased ectomycorrhizal persistence and diversity, and fine root biomass). Shifts in community structure occurred for micro-arthropods and bacteria, while no discernible impact was detected for decomposition rates and total collembola numbers.

- Nutrient leaching losses peaked between the second and third years after harvest. All other responses to the treatments continued until the end of the 5-year period of study.
- The centres of 1.0-ha and 10-ha openings were very similar in soil biological activity. The major influence of the forest edge occurred within approximately one-half of the tree canopy height of the uncut forest.
- Two factors important for seedling establishment and growth, nitrogen mineralization and establishment of ectomycorrhizae (albeit from nursery fungi present at out-planting) were well established in openings larger than 0.1 ha.
- Distance from the edge had a greater influence on the amount and diversity of active ectomycorrhizal inoculum than did opening size. Therefore, openings that have a high perimeter-to-area ratio or those with patches of trees throughout, will maintain the highest amounts and diversity of available ectomycorrhizal inoculum.
- The main effect of timber harvesting on micro-arthropods was a shift in community composition. At the family level, some micro-arthropod groups decreased in abundance while others increased. The significance of these shifts is unknown.
- Disturbing the forest by timber harvesting and then re-planting creates a different ecosystem: fine root and litter inputs become minute, nitrogen mineralization processes are altered, and the community structure of soil organisms changes. The implications of the observed changes are unknown at this stage. However, there was no evidence to suggest that soil biological processes ceased in the new ecosystem.
- Because specific organisms are affected differently by timber harvesting disturbance, and because we are unsure of the significance of observed changes, cutting practices that create a range of opening sizes would best maintain the widest variety of soil biological diversity and functions.

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