ROOTING PATTERNS

OF

BOREAL TREE SPECIES

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ABSTRACT

Concern over the impacts of harvesting and site preparation on soil processes and the successful reestablishment of new forests has resulted in a need for an understanding of the role root systems play in capturing potentially leached nutrients or how roots exploit various microsites created by a variety of site preparation techniques. The objectives of this study were to 1) investigate the rooting distribution of aspen and white spruce in an aged chronosequence of mixedwood stands and 2) determine the root activity of aspen and spruce in the litter and Bt horizons using a strontium tracer. Root distributions were determined by taking cores to 120 cm depth in 6, 10, 20, 60 and 110 year old mixedwood stands. Root activity was determined by applying strontium to $2m^2$ plots either on the litter or through augers holes at a 90 cm depth for the 10, 20 and 110 year old stands. Foliar samples from aspen, spruce, alder were collected over two growing seasons and analyzed for strontium. The majority of roots (50%) for each species were found in the LFH horizon for all sites. Root length decreased with soil depth which also corresponded to the low soil temperatures (5-7°C) found at 50 to 100 cm. Total root length for spruce and aspen increased with increasing stand age but generally decreased for grass and other understory species. Root activity was highest in the LFH horizon, with aspen roots being more active than spruce roots. Root activity was highest for the 10 year old stand. Increased foliar levels of Sr were found for the litter application in spruce, aspen and alder (site 1) for Sites 1 and 2; however, the Sr levels were slightly elevated for 80 year old aspen (Site 3) and no increased Sr levels for the 110 year old spruce after the second year. The application of Sr at a 90 cm depth was not observed for any species at the three sites after 2 years. These results suggest that aspen are quite competitive with spruce for below ground resources particularly in the LFH horizon and deep roots may play a role in maintaining basic soil conditions.

INTRODUCTION

Concern has been raised as to the impacts of harvesting and site preparation methods and in some cases fire events on the nutrient status of forest soils. Some forestry practices can be detrimental to nutrient levels in the soil by either removing surface mineral soil and litter layers such as in landings or through increased nutrient leaching following harvesting; hence reducing the productivity of a site for future tree rotations. The role of tree roots in capturing nutrients that may be potentially lost to nutrient leaching is not understood and Gale and Grigal (1987) suggested that early successional species (i.e., aspen) may be beneficial in minimizing nutrient loss due to their extensive root systems whereas late successional species (i.e., spruce) are better suited for sites where nutrient resources are concentrated near the soil surface. In the Boreal Mixedwood forests, however, little is known about the distribution and extent of aspen and spruce roots and where roots of each species exploit the soil profile for water and nutrients.

Root length measurements are necessary in order to understand the role of roots in the absorption of water and nutrients, especially from the standpoint of investigating nutrient competition between species. Roots that are actively involved in uptake are generally less than 3 mm in diameter. There are no studies, however, that have quantified root length densities for aspen and spruce in Boreal Mixedwood stands. Strong and La Roi (1983a) did quantify the number of roots on soil pit faces for various boreal species, but did not separate out species or determine root length densities. There has been some work done in Minnesota on root distributions of aspen in pure aspen stands (Ruark and Bockheim, 1987), but not a mixedwood stand.

The objectives of this project therefore were to 1) investigate the rooting distribution of

aspen and spruce trees in Boreal Mixedwood forests of various ages, and 2) determine the root activity for aspen and spruce in the forest floor and at a 90 cm depth using a strontium tracer.

MATERIAL AND METHODS

Site Description

Sites were established on Highway 2 (Site 1), Snowfield road (Site 2), Heritage Lake (Site 3), Meeyomoot Road (Site 4) and Prince Albert National Park (Site 5) (Fig. 1). Site l was clearcut in the winter of 1970 and during the winter of 1983 the site was lightly shearbladed (Table 1). Bareroot (3-0) white spruce seedlings were planted in the spring of 1984. The stand is approximately 101 years old and contained a mixture of white spruce and aspen. White spruce seedlings were released from aspen competition by brushsawing after year 5 (1989); however, aspen stocking was still high (Table 1). Site 2 was harvested in the summer of 1974 and planted with 2-2 bareroot white spruce seedlings in the fall of 1975. White spruce seedlings were also released from aspen competition by brushsawing in 1984. Site 3 is a mature stand of spruce and aspen (ca 110 year old spruce). Site 4 was harvested in the summer of 1987 and site prepared with the bracke mounder in 1987. The site was planted to 3-0 bareroot white spruce in the spring of 1988. The fifth site was located in the Prince Albert National Park south of Waskesiu Lake and consists of 60 year old white spruce and aspen trees. These sites are associated with the Waskesiu Hills Upland and the Montreal Lake Plain of the mixedwood ecodistrict (Kabzerns *et al*., 1988).

Soils at sites 1, 2 and 4 are dominated by Orthic Gray Luvisols with some Brunisolic Luvisols of the Loan River and Bittern Lake associations, respectively, Site 3 has Brunisolic Luvisol soils of the Bittern Lake association. At site 5, the general landscape is classified as a

Figure 1. Location of the sampling sites in the Prince Albert Model Forest.

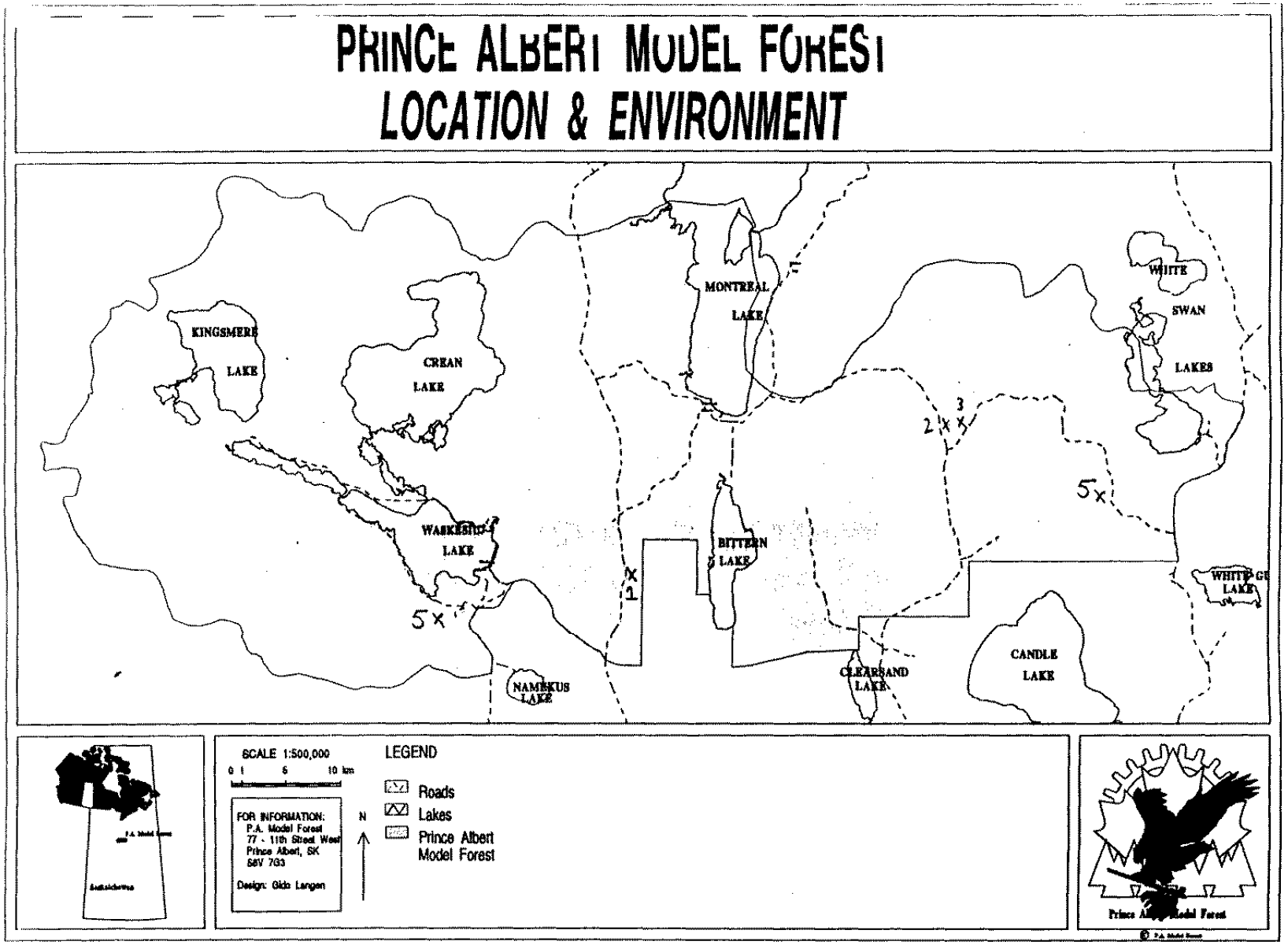


Table 1. Stand characteristics for the five Model Forest Sites

Site	Age yr	Height m	DBH cm	Stocking no ha^{-1}	Age yr	Height m	DBit cm	Stocking no ha^{-1}	Ecological Classification†
---- White Spruce ----					---- Trembling Aspen ----				
4	6	1.1	2.4	2173	6	2.5	3.5	8244	E23-d3.3/SM2:3r-10SCL
1	10	2.7	5.5	1982	5‡	2.8	3.2	11434	E21-d3.3/SM4:8d-20SiL
2	20	4.4	7.8	2478	20	4.9	5.8	2882	E23-d3.3/SM4:3r-10SiL
5	55	15.0	25.0	672	57	20.0	23.7	1415	E18-b3.1/SM1:3d-10SL
3	110	23.0	37.7	1168	85	20.7	25.6	2584	E23-d3.3/SM3:8r-10SiL

† Classification by Beckingham *et al*. (1996)

‡ Aspen was brushsawed at age 5 years

Loon River-Bittern Lake with a slope class of 3-5%. The research plot is dominated by Loon River (Orthic Gray Luvisolic) soils over 70% of the landscape with significant inclusions of Bittern Lake (Brunisolic Gray Luvisols, Eutric Brunisolic soils, and gleyed variants of the Luvisolic and Brunisolic orders in lower landscape positions). Soil chemical data for each site are presented in Appendix A.

The vegetation on the site consists predominantly of mature trembling aspen (*Populus tremuloides* Michx.) and white spruce (*Picea glauca* (Moench) Voss). Alder (*Alnus crispy* (Ait.) Pursch) was present at site 1 and at site 5, some balsam poplar (*Populus balsamifera* L.) was growing on the Gleysols in the depressional areas. Understory vegetation for site 1 consisted of smooth wild strawberry (*Fragaria virginiana* Duchesne), Canada blueberry (*Vaccinium myrtilloides* Michx.), grass species and prickly rose (*Rosa acicularis*); site 2 and 4 had low bush cranberry (*Vibuurnum edule* (Michx.) Raf.), Canada blueberry (*Vaccinium myrtilloides* Michx.), bunchberry (*Cornus canadensis* L.), tall lungwort (*Mertensia paniculata* (Alt.) G. Don) and grass species; Site 3 had bunchberry (*Corpus canadensis* L.), wild sarsaparilla (*Aralia nudicaulis* L.), dewberry (*Rubus pubescens* Raf.), palmate-leaved coltsfoot (*Petasites palmatus* (Ait.) A. Gray), stiff club moss (*Lycopodium annotinum* L.) and Knight's plume (*Ptilium crista-castrensis* (Hedw.) De Not.); and site 5 had prickly rose (*Rosy acicularis*), dry-spike sedge (*Carex siccata* Dewey) and bearberry (*Arctostaphylos uva-ursi* (L.) Spreng).

Root Sampling

Root distributions were taken with 8 cm diameter cores to a depth of 120 cm. Seven cores were taken from sites 1-4 in 1994 and 18 cores were collected from selected landscape positions to cover a range in soil type and landscape elements from site 5 in 1993. The first 0

to 15 cm increment was taken with a root auger, and the remaining 15 cm increments to 120 cm depth by a Riverside auger. Samples were stored at 4°C until processing. Soil samples were placed in meshed bags and rinsed in water to remove the soil; roots were then frozen until root lengths could be counted. Soil samples with high amounts of clay were soaked in water and frozen in order to disperse the clay aggregates prior to washing. Roots were separated by species (aspen, white spruce, grass and other [understory species]) and diameter class (< 2, 2-5 and > 5 mm). Root lengths were counted using the line-intercept technique (Newman, 1966) and the samples were then oven-dried and weighed.

Root Activity

Strontium, as strontium chloride ($SrCl_2$), was applied to 2 m^2 plots either on the forest floor or at a depth of 80 cm at sites 1-3 in 1994. The depth treatment was completed by augering 25 holes to a 80 cm depth and pouring the $SrCl_2$ down a tube so as not to contaminate the soil profile. Each plot received 200 g of $SrCl_2$ and was replicated three times. Foliage samples were collected from white spruce and aspen for all three sites and alder was also collected at Site 1 over two growing seasons. Foliage samples were digested (Thomas *et al*., 1967) and analyzed for Sr to determine root activity. Litter and FH horizons from all treatments were also collected in May 1995 to determine the input of Sr from litterfall to the litter layer. The litter samples were also digested and analyzed for Sr. Soil samples were also collected to a 100 cm depth in the control plots to determine natural levels of Ca and Sr with a 1M NH_4C1 extractant.

Soil Temperature and Moisture

Soil moisture and temperature probes were installed in pits (2, 20, 40, 80 and 100 cm)

at each site to measure some environmental variables that would be related to root activity. Soil moisture and temperature probes were measured during the summer and fall in 1994 and 1995 at sites 1, 2 and 3 and 4 to measure some environmental variables that would be related to root activity.

RESULTS

Root Distributions

Root length

Average root length was highest for grass, then other understory species followed by aspen and spruce for sites 1-4 (Table 2). Site 5, however, did not follow this trend with aspen having the highest average root length followed by other, grass and spruce (Table 2). Root length increased with stand age for spruce with site 5, however, not following the trend. Aspen root length decreased from 6 and 10 years to 20 years and increased again for the 60 year old stand with a decrease for the 110 year old stand. Grass and other species root length were highest in the 20 year old stand, followed by the 6, 10, 110 and 60 year old stands. The dramatic decrease in grass roots in the 60 and 110 year old stands is due to the shading effect of the overstory canopy.

Roots were found to a 120 cm depth with the majority of roots found in the forest floor (LFH horizon) (Table 3). For all sites, up to 60% of the root length density for all four species was found in the LFH layer (Table 3). Root length density decreased dramatically with soil depth and means, standard deviations and coefficient of variations by depth increment and site are presented in Appendix B. Root length at depths greater than 60 cm averaged 10 and 14% across sites for white spruce and trembling aspen roots, respectively (Table 3).

Within site 5, mean total root length per core was highest for the Brunisol soil and lowest for the Luvisol (Table 2). Per unit root length density, Brunisols had higher densities in the

Table 2.
Average root length to a 120 cm depth.

Site	Age	White Spruce	Trembling Aspen	Grass	Other	All
	years		---------- cm ----------			
4	6	104	575	16291	1420	4483
1	10	216	543	12833	2268	3965
2	20	333	281	17967	3628	5562
3	110	623	1017	3071	1812	1629
5L	60	187	1827	302	354	2670
5B	60	126	2413	550	539	3629
5G	60	114	1801	798	834	3547

Table 3.
Percentage of roots in various soil horizons

Horizon	Site	White Spruce	Trembling Aspen	Grass	Other	All
LFH	1	44	40	41	29	40
	2	52	46	31	55	36
	3	42	35	55	53	50
	4	43	41	40	44	40
	5L	52	60	48	59	58
	5B	94	68	75	61	69
	5G	82	54	68	38	54
0-10 cm	1	29	29	40	30	39
	2	34	25	23	22	23
	3	27	18	35	21	28
	4	25	18	21	25	22
	5L	20	13	27	15	15
	5B	5	13	5	6	11
	5G	4	9	6	6	8
60-120 cm	1	14	11	5	17	6
	2	3	8	13	9	12
	3	20	24	2	9	9
	4	11	14	2	11	4
	5L	21	8	8	10	9
	5B	2	5	0	9	5
	5G	0	25	2	5	15

forest floor but densities in Gleysols tended to be somewhat higher in the subsoils (Appendix B). Despite textural differences between the three soils, root length densities were very similar in the mineral soil.

Fine root length (< 2 mm dia.) comprised from 94 to 100% of the total root length for all species at the five sites (Appendix C). The larger diameter roots were associated with spruce and aspen.

A small correlation was found between total root length of spruce in the LFH and the number of trees within a 3 m radius of the soil core at site 5 (Rtl = 21.4 + 57.8(# trees), $r^2 = 0.59$); however, no significant correlation could be found for trembling aspen (Rtl = 465.7 + 140.4(# trees), $r^2 = 0.21$).

Root Weight

Root biomass generally increased with increasing stand age, however, site 5 did not follow this trend (Table 4). Grasses and other species showed the highest biomass with the 20 year old stand (Table 4). Of the four species measured, aspen had the largest biomass in the 60 year old stand and this was due to the large number of roots > 5 cm in diameter (Appendix C). Root weight densities by horizon for each site are presented in Appendix D.

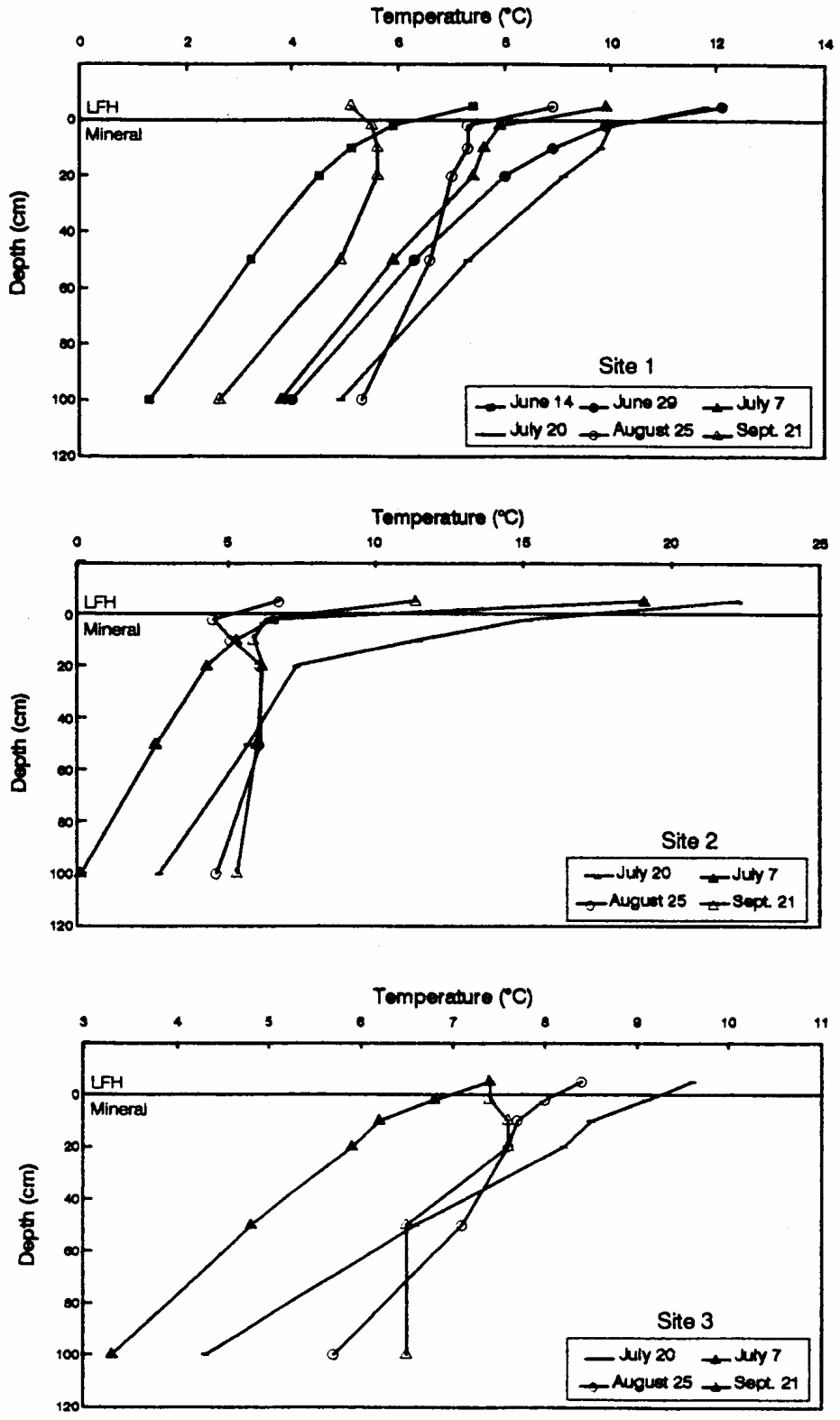
Soil Moisture and Temperature

Soil temperatures for sites 1, 2, and 3 ranged from 5 to 22°C in the forest floor and from 0 to 6.5°C at a 100 cm depth during the growing season in 1994. (Fig. 2). Soil temperatures in 1995 were similar except that temperatures were somewhat warmer deeper in the soil profile (Fig. 3). Soil moisture levels for the three sites in 1994 were low in the surface horizons throughout the summer and increased to 0.25-0.30 $cm^3\ cm^{-3}$ at a 100 cm depth (Fig. 4). In 1995, site 1 had

Table 4.
Average root biomass for the five sites (kg ha^{-1}).

Site	Age	White Spruce	Trembling Aspen	Grass	Other	All
4	6	255	1550	514	4588	1707
1	10	1333	4723	599	3673	2582
2	20	4044	6389	927	7889	4814
5L	60	1789	16917	287	547	19540
5B	60	627	9392	454	7544	18017
5G	60	295	10713	430	2030	13470
3	110	4826	5552	141	2556	3269

Figure 2. Soil temperatures for sites 1, 2 and 3 For the 1994 growing season.



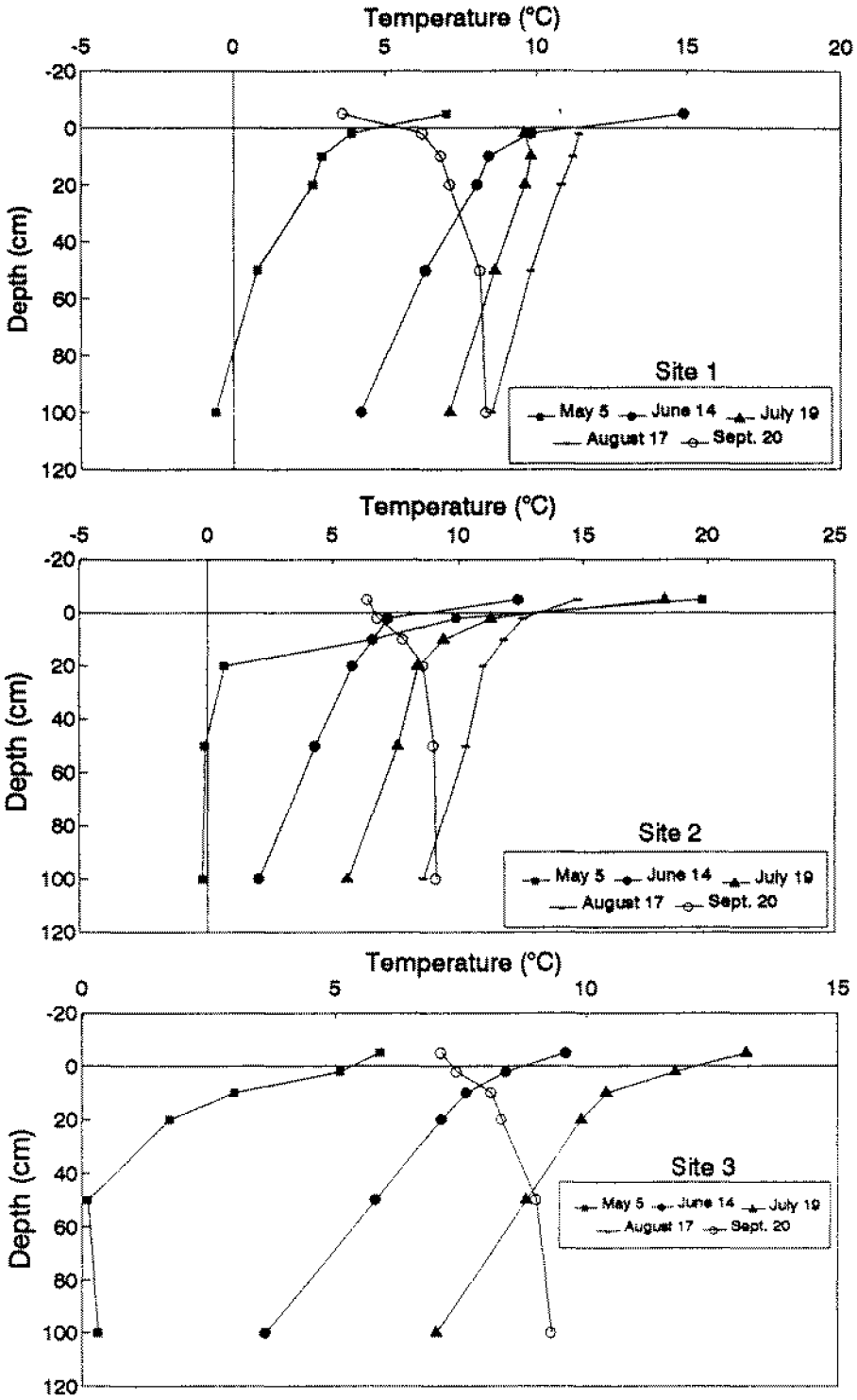
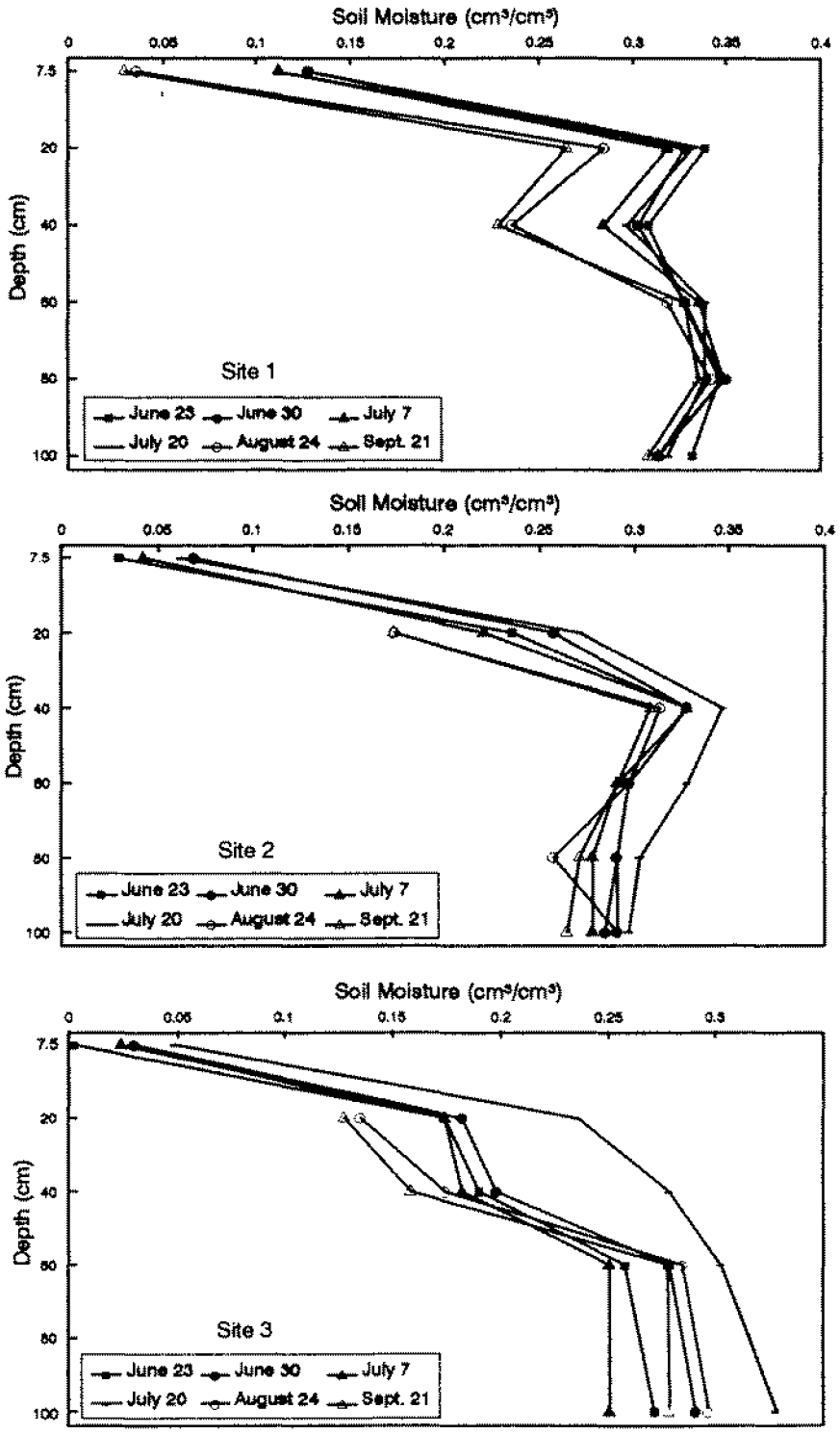


Figure 3. Soil temperatures for sites 1, 2 and 3 for the 1995 growing season.

Figure 4. Soil moisture for sites 1, 2 and 3 for the 1994 growing season.



higher water contents in the surface soils than sites 2 and 3 (Fig. 5). The 110 year old stand showed a reduction in soil moisture at the 80 cm depth compared to the other horizons.

Root Activity

Extractable levels of Sr in the control plots were highest in the forest floor for all sites compared to the mineral soil (Table 5). For the mineral soil, Sr concentrations were lowest in the 0-30 cm depths and then increased up to 4 $\mu g\ g^{-1}$ at a 90 cm depth. One year after the application of Sr, the concentrations of Sr in the L horizon was highest for the surface application of Sr (Table 6). The L horizon represents only the litter-fall from the past year and thus shows the rapid cycling of Sr from the forest floor in a years time. The depth and control treatments for the L horizons were very similar indicating that very little Sr was translocated from a 90 cm depth in the soil profile to the surface. This is important for the results of the second year because it indicates that there was no contamination of the forest floor from litter in the 90 cm depth treatment. The FH horizon also had the highest concentrations of Sr in the surface treatment and this probably reflects the application of Sr the previous year.

Strontium concentrations in tissues were variable within and between treatments (Table 7). Tissue concentrations for white spruce were not significantly different between treatments at each site. It is interesting to note that the surface treatment was 2 to 3 times larger than the control and depth treatment, respectively. Aspen roots showed the highest activity of all roots. Although the surface and depth treatments had strontium concentrations that were 24 and 16 times greater than the control at Site 1, respectively, they were not significantly different from each other. Site 2, however, showed that strontium concentrations, and hence root activity, for the surface and depth treatments were significantly higher than the control. At Site 3, strontium

Figure 5. Soil moisture for sites 1, 2 and 3 for the 1995 growing season.

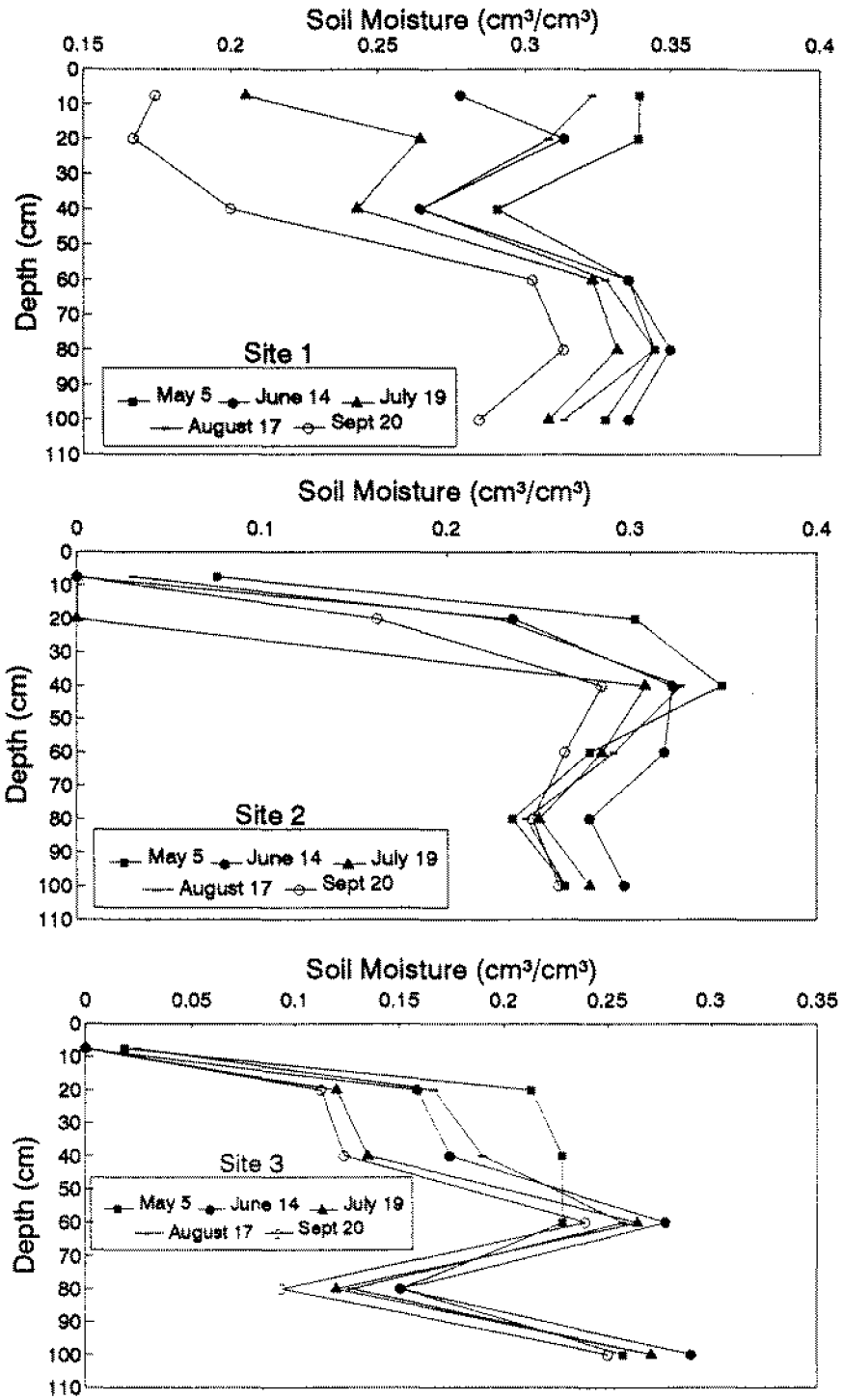


Table 5.
Concentration (µg g^{-1}) of strontium in the soil for the control plots of each site.

Depth	Site 1	Site 2	Site 3
LFH	19.47	20.10	12.13
0-15	0.77	1.15	0.49
15-30	0.79	3.37	0.90
30-45	1.95	3.89	2.19
45-60	3.22	4.15	2.75
60-75	3.04	3.93	2.76
75-90	2.80	3.78	2.48

Table 6.
Strontium concentrations (µg g^{-1}) in the L (litter) and FH horizons of the forest floor one year after strontium application.

Site	Treatment	L Horizon		FH Horizon	
		Sr	Ca	Sr	Ca
1	Surface	1254	12528	772	10866
	Deep	39	12810	46	11455
	Control	38	17414	28	9710
2	Surface	1435	15819	1248	11857
	Deep	50	24543	35	15328
	Control	47	25271	43	16006
3	Surface	1089	15665	1252	22400
	Deep	34	23862	50	43725
	Control	35	33046	40	31354

Table 7.
Difference in strontium concentration between first and last sampling date during first growing season.

Site	Treatment	Spruce	Aspen	Alder
		---------- μg g^{-1} ----------		
1	Surface	10.75a†	167.1 a	141.30a
	Depth	3.22a	108.9a	7.50a
	Control	5.08a	7. l a	7.88a
2	Surface	7.10a	37.40a	
	Depth	4.54a	26.97a	
	Control	6.53a	4.54b	
3	Surface	2.19a	7.07ab	
	Depth	5.25a	9.61a	
	Control	5.91a	4.17b	

† columns with the same letter for a site are not significantly different at P=0.05.

concentrations were significantly higher for the depth treatment compared to the control, Alder was found only at Site 1 and strontium concentrations for the surface treatment were 19 times larger than the depth and control; however, they were not significantly different. The strontium data indicates that spruce roots were fairly inactive in the surface and depth treatments compared to the control. Spruce roots were not abundant at the 90 cm depth possibly explaining the inactivity of the strontium at 90 cm; however, this reason cannot be used for the surface treatment due to the abundance of roots in the LHF horizon (Table 2). One explanation for the inactivity of the spruce roots could be that the roots of the competing vegetation (i.e., aspen, grass and other understory vegetation) were more efficient in absorbing strontium than white spruce. Aspen is known to be a high accumulator of calcium (strontium mimics calcium in the biological cycle) possibly explaining the high concentrations of strontium in the aspen foliage compared to the spruce trees. Aspen roots were also more active at the 90 cm depth treatment for all three sites, suggesting that aspen trees are important for capturing potentially leached nutrients as well as cycling nutrients from deep in the soil profile.

Second Year

The accumulation of Sr in the foliage (fall values-spring values) two years after application indicate that root were very active in the forest floor compared to the 90 cm depth treatment for all species at Sites 1 and 2 (Table 8). The aspen and alder had higher accumulations compared to the spruce trees. The mature stand (Site 3), however, showed little accumulation of Sr, more so by the aspen than the spruce and the small accumulations in the foliage are likely due to the dilution of the tracer in the large trees relative to the other sites. Strontium concentrations in the foliage collected in September 1995 also showed the same trend,

Table 8.
The difference in spring and fall strontium concentrations (µg g^{-1})
in foliage of spruce, aspen and alder two years after strontium application.

Site	Treatment	Spruce	Aspen	Alder
1	Surface	55.11a†	256.77a	183.41a
	Deep	6.11b	-.60b	7.76b
	Control	6.21b	13.37b	3.49b
2	Surface	17.42a	89.85a	
	Deep	9.88ab	17.84b	
	Control	7.85b	27.96b	
3	Surface	10.02a	17.63a	
	Deep	10.40a	12.62a	
	Control	9.17a	10.81a	

† columns with the same letter for a site are not significantly different at P=0.10.

however, the Sr concentrations of the foliage are more pronounced for the surface treatment especially for the aspen trees (Table 9).

Hydroponic Study

White spruce seedlings (Prince Albert Nursery 1.5-1.5) and aspen seedlings (Canadian Forest Service, Edmonton) were placed in an aerated hydroponic solution for 3 to 4 weeks. After this period, 10 ppm of Sr was added to the solution for a one week period. Seedlings were harvested, dried and ground; however, Sr analysis has not been completed for this report.

^{15}N Study

A small scale study was also done with ^{15}N to determine if an application of ^{15}N could be detected in the foliage of 10 year old trees (Table 10). The nitrogen tracer was found one week later in the foliage of all species except the alder. The alder was located on the edge of the plots; however, the lack of ^{15}N accumulation in the alder suggests that these trees are fixing a large quantity of nitrogen in order not to absorb the free source of nitrogen. Spruce trees tended to continue to absorb ^{15}N throughout the summer; however, the ^{15}N values for aspen remained constant. This data suggests that aspen trees are very efficient in absorbing and translocating nutrients compared to white spruce.

DISCUSSION

This study represents the first attempt to quantify root length and weight densities for individual species in Boreal mixedwood stands. Fine roots were found to a 1.2 m depth for all soil types and this compares with rooting depths in the literature for aspen stands which ranged from 1.5 to > 3 m and from 1.4 to 3 m for white spruce stands (Stone and Kalisz, 1991).

Table 9.
Strontium concentrations (µg g^{-1}) in foliage collected in the fall for spruce, aspen and alder two years after strontium application.

Site	Treatment	Spruce	Aspen	Alder
1	Surface	78.13	410.56	284.07
	Deep	10.20	35.20	20.00
	Control	10.60	26.27	13.93
2	Surface	25.07	134.13	
	Deep	13.27	38.30	
	Control	10.40	42.23	
3	Surface	14.27	30.63	
	Deep	15.30	23.60	
	Control	13.67	24.93	

Table 10.
Values of ^{15}N in foliage of spruce, aspen, alder and understory species. Nitrogen, as ^{15}N was applied immediately after the June 29 sampling.

Date		Spruce	Aspen	Alder
		-------- atom % ^{15}N excess ------		
June	29	0	0	0
July	7	0.027	0.058	0.003
July	16	0.027	0.060	0
July	20	0.035	0.059	0
Aug	24	0.068	0.060	0

Schultz (1969) also reported that taproots or sinkers of natural white spruce stands in Michigan, Wisconsin and Minnesota penetrated, on average to 0.92 m, with one sinker found to 1.8 m. White spruce roots penetrated deeper on sands than on sandy-loams and silt-loam soils (Schultz, 1969).

Fine root biomass expressed on an hectare basis for aspen in this study ranged from 2.89 to 55.46 Mg ha^{-1} with an average of 14.13 Mg ha^{-1} across all soils. This average is comparable to the estimate of 10.7 Mg ha^{-1} found for roots (< 30 mm dia.) of a 63 year old aspen stand by Ruark and Bockheim (1988). Belowground biomass for understory species (excluding spruce) ranged from 0.32 to 29.76 Mg ha^{-1} (avg = 3.0 Mg ha^{-1}) which is lower than the 10.1 Mg ha^{-1} reported by Ruark and Bockheim (1988). White spruce belowground biomass was considerably less than that for aspen and understory species averaging 1.3 Mg ha^{-1}; however, this value compares quite well with the 1.87 Mg ha^{-1} reported by Kimmins and Hawkes (1978) for a mixed stand of old-growth subalpine fir (*Abies lasiocarpa* (Hook.) Nutt.) and white spruce in British Columbia.

Roots at this site were concentrated in the forest floor. These findings coincide with those reported by Strong and La Roi (1985) for aspen (42-56%) and aspen/spruce (46%) stands. Kimmins and Hawkes (1978) also reported that 50% of the subalpine fir/white spruce roots were located in the LFH layer. In Finland, Kalela (1950) found that only 26% and 10% of the spruce and pine roots, respectively were located in the LFH. The high concentration of spruce or aspen roots in the forest floor is likely an adaptive strategy by these species since the main source of nutrients, water and warmest soil temperatures are in the forest floor layer. The high concentration of roots in the LFH also suggests the importance of this layer for future tree

rotations: hence the removal of this layer during harvesting and silvicultural practices should be minimized.

Roots of aspen, spruce and pine were found to a 120 cm depth with up to 26% of the aspen root length found below a 60 cm depth. Comerford *et al*. (1984) in a review of subsoil uptake by plant roots concluded that small root densities at depth can play a major role in water and nutrient uptake. Results of the tracer study would indicate that aspen roots were more active than spruce roots deeper in the soil profile. Work by Van Rees and Comerford (1986) showed that slash pine roots at a 1 m depth were quite effective in absorbing a tracer especially during the dry season. Wilson and Grigal (1995) suggested that Ca in subsoils played a minor role in providing Ca to the forest stand. However, the importance of aspen roots in subsoils to tree nutrition from this study is intriguing and the significance of these deep roots in nutrient cycling, particularly Ca will require further research.

The high percentage of roots in the LFH is also due to the higher soil temperatures (Fig. 4) in this layer and the favourably moisture conditions in the spring time (Fig. 5). Although there were roots at depth, the reduced root length densities at 100 cm depth may be due to the cool soil temperatures. Last year soil temperatures for all three sites were generally less than 6°C which is the temperature at which roots begin to initiate growth. Hence, soil temperatures in Luvisolic forest soils may be too cool to facilitate root growth deep in the soil profile. In 1994 soil temperatures for all three sites at 100 cm were generally less than 6°C which is the temperature at which roots begin to initiate growth. In 1995, soil temperatures were somewhat warmer approaching 10^{o}C (Figs. 2 and 3). The cool soil temperatures in Luvisolic forest soils may thus restrict deep root penetration and function.

The number of trembling aspen stems was twice that of white spruce for the study site; however, aspen root length was 10 times higher than that for spruce. This fact would suggest that aspen is a more nutrient demanding species than white spruce and supports the hypothesis of Strong and La Roi (1985) that climax species are less nutrient demanding than seral (aspen) species. However, spruce may have a more efficient mechanism for nutrient absorption and thus may not require a large root surface area.

CONCLUSIONS

This study is the first to attempt to quantify rooting distributions of both aspen and white spruce trees growing together in a mixedwood stand. Roots of both species were found to a depth of 1.2 m. Although there were textural differences between soil types at the research sites, root length densities in the mineral soil were very similar with soil depth. Roots of all species were concentrated in the LFH layer and gradually decreased with depth highlighting the importance of the forest floor in tree nutrition.

Recommendations for Enhancing the Nutrient Cycling and Silvicultural Aspects of Sustainable Ecosystem Management of the Prince Albert Model Forest.

Findings from this study concerning root distribution and activity would suggest that:

1. The disturbance to the forest floor during logging should be minimal to ensure a favourable medium for newly planted root systems as well as access for roots to easily mineralizable nutrients.

2. Maintaining the aspen component in mixedwood forests (i.e. aspen and spruce) would minimize acidification of these glacial tills by recycling calcium from deep in the soil profile by aspen roots.

3. Forest floor and surface soils removed next to roadways for landing areas should be scraped off and piled in different directions. When the logs have been processed, the landing should be ripped and the surface soil and forest floor pushed back onto the site to provide a better environment for seedling root growth.

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APPENDIX A
Soil physical and chemical data for the Model Forest sites

Table 1.
Soil physical and chemical data for sites 1-5 for the 0 to 15 cm depth†.

Soil	Bulk Density g cm^{-3}	Organic Carbon‡ (Mg/ha)	pH	CEC cmol kg^{-1}	Total Nitrogen (kg/ha)	Exchangeable‡	
						Calcium (kg/ha)	Potassium (kg/ha)
1	1.04	55	4.78	23.0	2046	4755	534
4	1.07	49	4.57	28.2	1691	4352	732
2	0.91	60	4.73	29.5	2052	3540	382
3	0.78	59	4.67	35.2	2022	4323	803
5	1.18	54	5.74	32.1	2513	8084	870

† This data was obtained from Pennock *et al*. (1996)

‡ Soil data is for the 0 to 45 cm depth.

APPENDIX B
Root Length Distributions by Depth Increment and Species

Table 2.
Total root length distribution in boreal forest soils

Depth (cm)	Spruce	Aspen	Grass	Other	Total
Luvisols	---------- Root length (cm/cm^3) 6-year-old (n=7) ----------				
0-3 (LFH)	0.2625	1.4215	24.3703	4.0091	30.4634
3-15	0.0378	0.1543	3.2877	0.5729	4.0527
15-30	0.0129	0.0671	1.6773	0.1490	1.9063
30-45	0.0043	0.0756	1.7842	0.0921	1.9561
45-60	0.0079	0.0470	1.1151	0.1124	1.2824
60-75	0.0062	0.0311	0.1139	0.0662	0.2174
75-90	0.0038	0.0292	0.0899	0.0410	0.1639
90-105	0.0027	0.0256	0.0551	0.0708	0.1541
105-120	0.0013	0.0086	0.0146	0.0133	0.0378
Luvisols	---------- Root length (cm/cm^3) 10-year-old (n=7) ----------				
0-4 (LFH)	0.4642	1.0599	26.7720	2.9049	31.2010
4-15	0.1099	0.2827	9.4711	1.1187	10.9825
15-30	0.0216	0.0960	1.5611	0.3086	1.9872
30-45	0.0076	0.0238	0.4683	0.1822	0.6820
45-60	0.0094	0.0235	0.3494	0.1752	0.5575
60-75	0.0190	0.0421	0.2938	0.2189	0.5739
75-90	0.0114	0.0184	0.2238	0.1163	0.3700
90-105	0.0040	0.0106	0.0982	0.0652	0.1780
105-120	0.0040	0.0071	0.1616	0.0495	0.2223
Luvisols	---------- Root length (cm/cm^3) 20-year-old (n=7) ----------				
0-5 (LFH)	0.7303	0.5568	22.2341	8.4310	31.9523
5-15	0.2352	0.1510	8.0946	1.7016	10.1824
15-30	0.0438	0.0422	3.5319	0.3363	3.9542
30-45	0.0089	0.0194	2.8489	0.2665	3.1436
45-60	0.0038	0.0246	1.7391	0.1338	1.9013
60-75	0.0035	0.0202	1.8263	0.2046	2.0545
75-90	0.0046	0.0062	0.6927	0.1314	0.8349
90-105	0.0014	0.0011	0.3055	0.0678	0.3758
105-120	0.0017	0.0022	0.2579	0.0295	0.2914
Luvisols	---------- Root length (cm/cm^3) 110-year-old (n=7) ----------				
0-5 (LFH)	0.9223	1.3893	6.9165	3.5573	12.7854
5-15	0.3012	0.3505	2.2009	0.6923	3.5450
15-30	0.0148	0.1019	0.2250	0.2414	0.5831
30-45	0.0344	0.0800	0.0451	0.0679	0.2275
45-60	0.0330	0.1295	0.0531	0.0732	0.2888
60-75	0.0563	0.1263	0.0701	0.0708	0.3236
75-90	0.0536	0.0938	0.0305	0.0665	0.2444
90-105	0.0178	0.0871	0.0000	0.0327	0.1376
105-120	0.0162	0.0157	0.0000	0.0256	0.0575

Table 2.
Total root length distribution in boreal forest soils (Continued)

Depth (cm)	Spruce	Aspen	Grass	Other	Total
	---------- Root length (cm/cm^3) 60-year-old ----------				
			Bruntisols (n=5)		
0-6 (LFH)	0.3687	5.9600	1.5635	1.1700	9.0622
6-15	0.0119	0.7841	0.0728	0.0797	0.9485
15-30	0.0000	0.2671	0.1295	0.0573	0.4540
30-45	0.0000	0.1300	0.0369	0.0818	0.2487
45-60	0.0000	0.0951	0.0040	0.0413	0.1404
60-75	0.0029	0.0896	0.0000	0.0624	0.1548
75-90	0.0000	0.0589	0.0000	0.0038	0.0627
90-105	0.0000	0.0140	0.0000	0.0016	0.0156
105-120	0.0000	0.0056	0.0000	0.0000	0.0056
			Gleysols (n=2)		
0-9 (LFH)	0.3117	2.1861	0.9461	0.7498	4.1937
9-15	0.0250	0.5416	0.1333	0.1783	0.8783
15-30	0.0194	0.1067	0.1167	0.5255	0.7683
30-45	0.0078	0.1006	0.0750	0.0717	0.2550
45-60	0.0039	0.0711	0.0083	0.0072	0.0906
60-75	0.0000	0.2172	0.0078	0.0239	0.2489
75-90	0.0000	0.2578	0.0083	0.0139	0.2800
90-105	0.0000	0.1050	0.0000	0.0183	0.1233
105-120	0.0000	0.0372	0.0044	0.0000	0.0417
			Luvisols (n=11)		
0-4 (LFH)	0.5785	5.9914	0.7684	1.1477	8.4860
4-15	0.0809	0.4564	0.1558	0.1070	0.8001
15-30	0.0142	0.2205	0.0528	0.0343	0.3219
30-45	0.0042	0.1484	0.0236	0.0290	0.2052
45-60	0.0026	0.1275	0.0136	0.0201	0.1638
60-75	0.0411	0.0829	0.0072	0.0257	0.1569
75-90	0.0039	0.0695	0.0039	0.0159	0.0932
90-105	0.0114	0.0375	0.0011	0.0050	0.0550
105-120	0.0047	0.0260	0.0031	0.0018	0.0357

t Proportion of root length in each depth.

Table 2a. Total root length distribution (Mean, Standard deviation and C.V.%) in boreal forest soils

Depth	Spruce			Aspen			Grass			Other			
(cm)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Total
Luvisols	---------- Root length (cm/cm^3) 6-year-old (n=7) ----------												
LFH	0.263	0.17	65	1.421	0.58	41	24.370	40.03	164	4.409	2.41	60	30.063
0-15	0.038	0.03	88	0.154	0.08	54	3.288	4.29	130	0.573	0.35	61	4.053
15-30	0.013	0.02	121	0.067	0.05	69	1.677	2.44	146	0.149	0.22	150	1.906
30-45	0.004	0.00	102	0.076	0.05	72	1.784	3.05	171	0.092	0.04	44	1.956
45-60	0.008	0.01	151	0.047	0.03	56	1.115	1.93	173	0.112	0.09	80	1.282
150-75	0.006	0.01	122	0.031	0.03	99	0.114	0.30	265	0.066	0.03	40	0.217
75-90	0.004	0.00	74	0.029	0.02	77	0.090	0.24	265	0.041	0.03	74	0.164
90-105	0.003	0.00	101	0.026	0.05	192	0.055	0.00	0	0.071	0.04	53	0.154
105-120	0.001	0.00	155	0.009	0.01	79	0.015	0.00	0	0.013	0.01	65	0.038
Luvisols	---------- Root length (cm/cm^3) 10-year-old (n=7) ----------												
LFH	0.464	0.22	47	1.060	0.68	64	26.772	26.21	98	2.905	2.07	71	31.201
0-15	0.110	0.06	55	0.283	0.17	60	9.471	11.02	116	1.119	0.33	29	10.982
15-30	0.022	0.03	119	0.096	0.06	58	1.561	1.63	105	0.309	0.19	62	1.987
30-45	0.008	0.01	174	0.024	0.01	45	0.468	0.40	86	0.182	0.10	54	0.682
45-60	0.009	0.02	171	0.023	0.01	45	0.349	0.27	77	0.175	0.10	58	0.558
60-75	0.019	0.01	74	0.042	0.03	69	0.294	0.25	85	0.219	0.12	56	0.574
75-90	0.011	0.01	118	0.018	0.01	44	0.224	0.23	103	0.116	0.03	29	0.370
90-105	0.004	0.01	186	0.011	0.01	74	0.098	0.12	120	0.065	0.04	56	0.178
1135-120	0.004	0.01	174	0.007	0.01	80	0.162	0.19	118	0.050	0.03	55	0.222
Luvisols	---------- Root length (cm/cm^3) 20-year-old (n=7) ----------												
LFH	0.730	0.35	47	0.557	0.31	56	22.234	44.03	198	8.431	5.46	65	31.952
0-15	0.235	0.17	70	0.151	0.09	61	8.095	13.59	168	1.702	0.97	57	10.182
15-30	0.044	0.07	168	0.042	0.03	77	3.532	6.17	175	0.336	0.21	63	3.954
30-45	0.009	0.01	58	0.019	0.02	101	2.849	5.37	188	0.266	0.23	85	3.144
45-60	0.004	0.00	86	0.025	0.02	91	1.739	3.00	172	0.134	0.06	47	1.901
60-75	0.003	0.00	87	0.020	0.02	98	1.826	2.35	129	0.205	0.16	80	2.055
75-90	0.005	0.00	99	0.006	0.01	156	0.693	0.72	105	0.131	0.07	55	0.835
90-105	0.001	0.00	172	0.001	0.00	173	0.306	0.48	156	0.068	0.03	39	0.376
105-120	0.002	0.00	127	0.002	0.00	224	0.258	0.34	130	0.030	0.02	54	0.291
Luvisols	---------- Root length (cm/cm^3) 110-year-old (n=7) ----------												
LFH	0.922	0.79	86	1.389	1.64	118	6.917	10.05	145	3.557	3.61	102	12.785
0-15	0.301	0.21	69	0.351	0.48	136	2.201	1.66	75	0.692	0.78	113	3.545
15-30	0.015	0.02	139	0.102	0.08	76	0.225	0.32	143	0.241	0.16	65	0.583
30-45	0.034	0.04	111	0.080	0.07	90	0.045	0.08	188	0.068	0.04	63	0.228
45-60	0.033	0.04	114	0.130	0.13	100	0.053	0.08	145	0.073	0.05	68	0.289
60-75	0.056	0.08	136	0.126	0.23	178	0.070	0.13	181	0.071	0.04	62	0.324
75-90	0.054	0.07	123	0.094	0.15	155	0.030	0.04	133	0.067	0.06	90	0.244
90-105	0.018	0.02	104	0.087	0.16	179	0.000	0.00	0	0.033	0.04	135	0.138
105-120	0.016	0.04	265	0.016	0.03	218	0.000	0.00	0	0.026	0.05	178	0.058

Table 2a.
Total root length distribution (Mean, Standard deviation and C.V. %)
in boreal forest soils (Continued)

Depth	Spruce			Aspen			Grass			Other			
(cm)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Total
	---------- Root length (cm/cm^3) 60-year-old ----------												
	Brunisols (n=5)												
LFH	0.369	0.50	135	5.960	2.80	47	1.564	1.90	121	1.170	1.02	87	9.062
0-15	0.012	0.02	139	0.784	0.49	62	0.073	0.09	119	0.080	0.14	172	0.948
15-30	0.000	0.00	0	0.267	0.13	47	0.130	0.15	117	0.057	0.07	126	0.454
30-45	0.000	0.00	0	0.130	0.14	106	0.037	0.08	224	0082	0.11	140	0.249
45-60	0.000	0.00	0	0.095	0.13	137	0.004	0.01	224	0.041	0.03	83	0.140
60-75	0.003	0.01	224	0.090	0.07	82	0.000	0.00	0	0.062	0.12	193	0.155
75-90	0.000	0.00	0	0.059	0.11	181	0.000	0.00	0	0.004	0.01	178	0.063
90-105	0.000	0.00	0	0.014	0.02	126	0.000	0.00	0	0.002	0.00	224	0.016
105-120	0.000	0.00	0	0.006	0.01	224	0.000	0.00	0	0.000	0.00	0	0.006
	Gleysols (n=2)												
LFH	0312	0.44	141	2.186	0.04	2	0.946	1.34	141	0.750	0.34	46	4.194
0-15	0.025	0.04	141	0.542	0.14	26	0.133	0.19	141	0.178	0.05	30	0.878
15-30	0.019	0.03	141	0.107	0.12	109	0.117	0.16	141	0.526	0.59	112	0.768
30-45	0.008	0.01	141	0.101	0.12	118	0.075	0.11	141	0.072	0.10	141	0.255
45-60	0.004	0.01	141	0.071	0.09	130	0.008	0.01	141	0.007	0.01	141	0.091
60-75	0.000	0.00	0	0.217	0.23	106	0.008	0.01	141	0.074	0.02	82	0.249
75-90	0.000	0.00	0	0.258	0.27	105	0.008	0.01	141	0.014	0.02	141	0.280
90-105	0.000	0.00	0	0.105	0.07	71	0.000	0.00	0	0.018	0.02	90	0.123
105-120	0.000	0.00	0	0.037	0.00	11	0.004	0.01	141	0.000	0.00	0	0.042
	Luvisols (n=11)												
LFH	0.578	0.54	94	5.991	4.27	71	0.768	0.77	101	1.148	0.82	71	8.486
0-15	0.081	0.12	152	0.456	0.27	58	0.156	0.23	147	0.107	0.12	114	0.800
15-30	0.014	0.03	203	0.220	0.11	51	0.053	0.11	217	0.034	0.06	173	0.322
30-45	0.004	0.01	284	0.148	0.13	87	0.024	0.06	271	0.029	0.04	140	0.205
45-60	0.003	0.01	269	0.127	0.10	82	0.014	0.04	273	0.020	0.02	120	0.164
60-75	0.041	0.05	128	0.083	0.08	96	0.007	0.02	332	0.026	0.05	179	0.157
75-90	0.004	0.01	223	0.069	0.07	95	0.004	0.01	332	0.016	0.03	199	0.093
90-105	0.011	0.03	226	0.037	0.04	101	0.001	0.00	332	0.005	0.01	239	0.055
105-120	0.005	0.02	332	0.026	0.04	149	0.003	0.00	0	0.002	0.01	332	0.036

APPENDIX C
Root Length Distributions by Diameter class, Depth Increment and Species

Table 1.
Root length distribution in boreal forest soils

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 4	---------- Root length (cm/cm^3) 6-year-old (n=7) ----------														
0-3 (I.FH)	0.253	0.000	0.000	1.413	0.009	0.000	24.34	0.031	0.000	3.961	0.000	0.000	29.98	0.088	0.000
3-15	0.038	0.000	0.000	0.148	0.006	0.000	3.287	0.001	0.000	0.563	0.003	0.006	4.036	0.010	0.006
15-30	0.013	0.000	0.000	0.065	0.003	0.000	1.577	0.000	0.000	0.149	0.000	0.000	1.904	0.003	0.001
30-45	0.004	0.000	0.000	0.074	0.002	0.000	1.784	0.000	0.000	0.092	0.000	0.000	1.954	0.002	0.000
45-60	0.008	0.000	0.000	0.047	0.000	0.000	1.115	0.000	0.000	0.112	0.000	0.000	1.282	0.000	0.000
60-75	0.005	0.001	0.000	0.031	0.000	0.000	0.114	0.000	0.000	0.066	0.000	0.000	0.216	0.001	0.000
75-90	0.004	0.000	0.000	0.029	0.000	0.000	0.090	0.000	0.000	0.041	0.000	0.000	0.164	0.000	0.000
90-105	0.003	0.000	0.000	0.026	0.000	0.000	0.055	0.000	0.000	0.071	0.000	0.000	0.154	0.000	0.000
105-120	0.001	0.000	0.000	0.009	0.000	0.000	0.015	0.000	0.000	0.013	0.000	0.000	0.038	0.000	0.000
Site 1	---------- Root length (cm/cm^3) 10-year-old (n=7) ----------														
0-4 (I.FH)	0.456	0.008	0.000	1.019	0.041	0.000	26.77	0.000	0.000	2.804	0.101	0.000	31.05	0.150	0.000
0-15	0.105	0.005	0.000	0.246	0.030	0.006	9.471	0.000	0.000	1.114	0.005	0.000	10.94	0.040	0.006
15-30	0.020	0.002	0.000	0.093	0.003	0.000	1.561	0.000	0.000	0.309	0.000	0.000	1.982	0.006	0.000
30-45	0.005	0.000	0.003	0.024	0.000	0.000	0.468	0.000	0.000	0.182	0.000	0.000	0.679	0.000	0.003
45-60	0.009	0.000	0.000	0.023	0.000	0.000	0.349	0.000	0.000	0.175	0.000	0.000	0.558	0.000	0.000
60-75	0.013	0.002	0.003	0.042	0.000	0.000	0.294	0.000	0.000	0.219	0.000	0.000	0.568	0.002	0.003
75-90	0.010	0.002	0.000	0.018	0.000	0.000	0.224	0.000	0.000	0.116	0.000	0.000	0.368	0.002	0.000
90-105	0.004	0.000	0.000	0.011	0.000	0.000	0.098	0.000	0.000	0.065	0.000	0.000	0.178	0.000	0.000
105-120	0.004	0.000	0.000	0.007	0.000	0.000	0.162	0.000	0.000	0.050	0.000	0.000	0.222	0.000	0.000
Site 2	---------- Root length (cm/cm^3) 20-year-old (n=7) ----------														
0-5 (LFH)	0.651	0.060	0.020	0.381	0.149	0.026	22.23	0.000	0.000	8.304	0.096	0.031	31.57	0.305	0.077
5-15	0.205	0.027	0.003	0.125	0.020	0.006	8.095	0.000	0.000	1.700	0.002	0.000	10.12	0.049	0.009
15-30	0.039	0.005	0.000	0.033	0.003	0.006	3.532	0.000	0.000	0.336	0.000	0.000	3.941	0.008	0.006
30-45	0.009	0.000	0.000	0.015	0.004	0.000	2.849	0.000	0.000	0.266	0.000	0,000	3.139	0.004	0.000
45-60	0.003	0.001	0.000	0.024	0.001	0.000	1.739	0.000	0.000	0.134	0.000	0.000	1.899	0.002	0.000
60-75	0.003	0.000	0.000	0.016	0.004	0.000	1.826	0.000	0.000	0.203	0.002	0.000	2.049	0.006	0.000
75-90	0.005	0.000	0.000	0.006	0.000	0.000	0.693	0.000	0.000	0.131	0.000	0.000	0.835	0.000	0.000
90-105	0.001	0.000	0.000	0.001	0.000	0.000	0.306	0.000	0.000	0.068	0.000	0.000	0.376	0.000	0.000
105-120	0.002	0.000	0.000	0.002	0.000	0.000	0.258	0.000	0.000	0.030	0.000	0.000	0.291	0.000	0.000
Site 3	---------- Root length (cm/cm^3) 110-year-old (n=7) ----------														
0-5 (LFH)	0.837	0.068	0.017	1.340	0.050	0.000	6.917	0.000	0.000	3.526	0.031	0.000	12.62	0.149	0.017
5-15	0.290	0.011	0.000	0.324	0.027	0.000	2.201	0.000	0.000	0.685	0.007	0.000	3.500	0.045	0.000
15-30	0.015	0.000	0.000	0.098	0.003	0.001	0.225	0.000	0.000	0.241	0.000	0.000	0.579	0.003	0.001
30-45	0.024	0.010	0.000	0.070	0.010	0.000	0.045	0.000	0.000	0.068	0.000	0.000	0.207	0.020	0.000
45-60	0.028	0.005	0.000	0.130	0.000	0.000	0.053	0.000	0.000	0.073	0.000	0.000	0.284	0.005	0.000
60-75	0.054	0.003	0.000	0.124	0.002	0.000	0.070	0.000	0.000	0.070	0.001	0.000	0.318	0.006	0.000
75-90	0.044	0.010	0.000	0.094	0.000	0.000	0.030	0.000	0.000	0.067	0.000	0.000	0.235	0.010	0.000
90-105	0.016	0.002	0.000	0.086	0.001	0.000	0.000	0.000	0.000	0.033	0.000	0.000	0.135	0.003	0.000
105-120	0.014	0.002	0.000	0.016	0.000	0.000	0.000	0.000	0.000	0.026	0.000	0.000	0.056	0.002	0.000

Table 1.
Root length distribution in boreal form soils (Continued)

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 5	---------- Root length (cm/cm^3) 60-year-old ----------														
	Brunisols (n=5)														
0-6 (LFH)	0.360	0.008	0.000	5.944	0.008	0.008	1.564	0.000	0.000	1.168	0.002	0.000	9.036	0.018	0.008
6-15	0.012	0.000	0.000	0.770	0.000	0.014	0.073	0.000	0.000	0.080	0.000	0.000	0.934	0.000	0.014
15-30	0.000	0.000	0.000	0.267	0.000	0.000	0.130	0.000	0.000	0.057	0.000	0.000	0.454	0.000	0.000
30-45	0.000	0.000	0.000	0.112	0.012	0.005	0.037	0.000	0.000	0.082	0.000	0.000	0.231	0.012	0.005
45-60	0.000	0.000	0.000	0.095	0.000	0.000	0.004	0.000	0.000	0.041	0.000	0.000	0.140	0.000	0.000
60-75	0.003	0.000	0.000	0.087	0.002	0.000	0.000	0.000	0.000	0.062	0.000	0.000	0.152	0.002	0.000
75-90	0.000	0.000	0.000	0.059	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.063	0.000	0.000
90-105	0.030	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.002	0.000	0.000	0.016	0.000	0.000
105-120	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000
	Gleysols (n=2)														
0-9 (LFH)	0.312	0.000	0.000	2.133	0.000	0.053	0.946	0.000	0.000	0.750	0.000	0.000	4.140	0.000	0.053
9-15	0.025	0.000	0.000	0.527	0.015	0.000	0.133	0.000	0.000	0.178	0.000	0.000	0.863	0.015	0.000
15-30	0.019	0.000	0.000	0.107	0.000	0.000	0.117	0.000	0.000	0.526	0.000	0.000	0.768	0.000	0.000
30-45	0.108	0.000	0.000	0.101	0.000	0.000	0.075	0.000	0.000	0.072	0.000	0.000	0.255	0.000	0.000
45-60	0.004	0.000	0.000	0.071	0.000	0.000	0.008	0.000	0.000	0.007	0.000	0.000	0.091	0.000	0.000
60-75	0.000	0.000	0.000	0.201	0.017	0.000	0.008	0.000	0.000	0.024	0.000	0.000	0.232	0.017	0.000
75-90	0.000	0.000	0.000	0.258	0.000	0.000	0.008	0.000	0.000	0.014	0.000	0.000	0.280	0.000	0.000
90-105	0.000	0.000	0.000	0.105	0.000	0.000	0.000	0.000	0.000	0.018	0.000	0.000	0.123	0.000	0.000
105-120	0.000	0.000	0.000	0.037	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.000	0.042	0.000	0.000
	Luvisols (n-11)														
0-4 (LFH)	0.550	0.029	0.000	5.972	0.005	0.014	0.768	0.000	0.000	1.148	0.000	0.000	8.437	0.034	0.014
4-15	0.077	0.004	0.000	0.428	0.007	0.021	0.156	0.000	0.000	0.106	0.001	0.000	0.766	0.013	0.021
15-30	0.011	0.003	0.000	0.208	0.004	0.009	0.053	0.000	0.000	0.034	0.000	0.000	0.306	0.007	0.009
30-45	0.004	0.000	0.000	0.140	0.002	0.007	0.024	0.000	0.000	0.029	0.000	0.000	0.197	0.002	0.007
45-60	0.003	0.000	0.000	0.117	0.003	0.007	0.014	0.000	0.000	0.020	0.000	0.000	0.153	0.003	0.007
60-75	0.038	0.003	0.000	0.079	0.004	0.000	0.007	0.000	0.000	0.026	0.000	0.000	0.150	0.007	0.000
75-90	0.004	0.000	0.000	0.066	0.000	0.003	0.004	0.000	0.000	0.016	0.000	0.000	0.090	0.000	0.003
90-105	0.011	0.000	0.000	0.037	0.000	0.000	0.001	0.000	0.000	0.005	0.000	0.000	0.055	0.000	0.000
105-120	0.005	0.000	0.000	0.026	0.000	0.000	0.003	0.000	0.000	0.002	0.000	0.000	0.036	0.000	0.000

Table 1a.
Root length distribution (Stdev) in boreal forest soils

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 4	---------- Root length (cm/cm^3) 6-year-old (n=7) ----------														
0-3 (LFH)	0.19	0.00	0.00	1.52	0.02	0.00	31.42	0.08	0.00	3.20	0.07	0.00	33.39	0.09	0.00
0-15	0.03	0.00	0.00	0.18	0.01	0.00	2.76	0.00	0.00	0.54	0.01	0.02	2.77	0.01	0.02
15-30	0.02	0.00	0.00	0.06	0.01	0.00	2.41	0.00	0.00	0.10	0.00	0.00	2.45	0.01	0.00
30-45	0.01	0.00	0.00	0.06	0.00	0.00	3.35	0.00	0.00	0.07	0.00	0.00	3.40	0.00	0.00
45-60	0.01	0.00	0.00	0.06	0.00	0.00	1.61	0.00	0.00	0.08	0.00	0.00	1.59	0.00	0.00
60-75	0.01	0.00	0.00	0.05	0.00	0.00	0.21	0.00	0.00	0.03	0.00	0.00	0.22	0.00	0.00
75-90	0.00	0.00	0.00	0.05	0.00	0.00	0.12	0.00	0.00	0.04	0.00	0.00	0.15	0.00	0.00
90-105	0.00	0.00	0.00	0.05	0.00	0.00	0.12	0.00	0.00	0.10	0.00	0.00	0.26	0.00	0.00
105-120	0.00	0.00	0.00	0.02	0.00	0.00	0.44	13.00	0.00	0.02	0.00	0.00	0.06	0.00	0.00
Site 1	---------- Root length (cm/cm^3) 10-year-old (n=7) ----------														
0-4 (LFH)	0.20	0.02	0.00	0.60	0.09	0.00	26.21	0.00	0.00	1.83	0.10	0.00	0.22	0.02	0.00
0-15	0.05	0.01	0.00	0.15	0.02	0.02	11.02	0.00	0.00	0.32	0.01	0.00	0.06	0.02	0.00
15-30	0.02	0.00	0.00	0.06	0.01	0.00	1.63	0.00	0.00	0.19	0.00	0.00	0.02	0.00	0.00
30-45	0.01	0.00	0.01	0.01	0.00	0.00	0.40	0.00	0.00	0.10	0.00	0.00	0.01	0.00	0.01
45-60	0.02	0.00	0.00	0.01	0.00	0.00	0.27	0.00	0.00	0.10	0.00	0.00	0.01	0.00	0.00
60-75	0.01	0.01	0.01	0.03	0.00	0.00	0.25	0.00	0.00	0.12	0.00	0.00	0.01	0.01	0.01
75-90	0.01	0.00	0.00	0.01	0.00	0.00	0.23	0.00	0.00	0.03	0.00	0.00	0.01	0.00	0.00
90-105	0.01	0.00	0.00	0.01	0.00	0.00	0.12	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00
105-120	0.01	0.00	0.00	0.01	0.00	0.00	0.19	0.00	0.00	0.03	0.00	0.00	0.00	0.00	0.00
Site 2	---------- Root length (cm/cm^3) 20-year-old (n=7) ----------														
0-5 (LFH)	0.31	0.06	0.04	0.34	0.26	0.05	36.25	0.00	0.00	2.34	0.13	0.08	25.23	0.15	0.00
0-15	0.11	0.03	0.01	0.05	0.02	0.02	15.26	0.00	0.00	0.93	0.00	0.00	11.16	0.03	0.02
15-30	0.06	0.01	0.00	0.02	0.01	0.02	6.17	0.00	0.00	0.21	0.00	0.00	1.60	0.01	0.00
30-45	0.01	0.00	0.00	0.01	0.01	0.00	5.37	0.00	0.00	0.23	0.00	0.00	0.47	0.00	0.01
45-60	0.00	0.00	0.00	0.02	0.00	0.00	3.00	0.00	0.00	0.06	0.00	0.00	0.24	0.00	0.00
60-75	0.00	0.00	0.00	0.02	0.01	0.00	2.35	0.00	0.00	0.16	0.01	0.00	0.20	0.01	0.01
75-90	0.00	0.00	0.00	0.01	0.00	0.00	0.72	0.00	0.00	0.07	0.00	0.00	0.23	0.00	0.00
90-105	0.00	0.00	0.00	0.00	0.00	0.00	0.48	0.00	0.00	0.03	0.00	0.00	0.13	0.00	0.00
105-120	0.00	0.04	0.00	0.00	0.00	0.00	0.34	0.00	0.00	0.02	0.00	0.00	0.19	0.00	0.00
Site 3	---------- Root length (cm/cm^3) 110-year-old (n=7) ----------														
0-5 (LFH)	0.76	0.08	0.03	0.58	0.05	0.00	11.36	0.00	0.00	3.54	0.04	0.00	10.63	0.08	0.03
0-15	0.79	0.03	0.00	0.37	0.06	0.00	5.04	0.00	0.00	0.54	0.02	0.00	2.91	0.04	0.00
15-30	0.05	0.00	0.00	0.25	0.02	0.01	0.92	0.00	0.00	0.88	0.00	0.00	0.46	0.01	0.00
30-45	0.10	0.07	0.00	0.21	0.05	0.00	0.20	0.00	0.00	0.11	0.00	0.00	0.13	0.02	0.00
45-60	0.14	0.05	0.00	0.23	0.00	0.00	0.23	0.00	0.00	0.16	0.00	0.00	0.18	0.02	0.00
60-75	0.25	0.01	0.00	0.48	0.02	0.00	0.56	0.00	0.00	0.09	0.01	0.00	0.29	0.01	0.00
75-90	0.12	0.05	0.00	0.24	0.00	0.00	0.24	0.00	0.00	0.13	0.00	0.00	0.16	0.01	0.00
90-105	0.04	0.01	0.00	0.41	0.01	0.00	0.00	0.00	0.00	0.08	0.00	0.00	0.18	0.00	0.00
105-120	0.06	0.02	0.00	0.06	0.00	0.00	0.00	0.00	0.00	0.05	0.00	0.013	0.04	0.00	0.00

Table 1a.
Root length distribution (Stdev) in boreal forest soils (Continued)

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 5	---------- Root length (cm/cm^3) 60-year-old ----------														
	Brunisols (n=5)														
LFH	0.48	0.02	0.00	2.81	0.02	0.02	1.90	0.00	0.00	1.08	0.01	0.00	4.57	0.03	0.02
0-15	0.02	0.00	0.00	0.48	0.00	0.03	0.07	0.00	0.00	0.11	0.00	0.00	0.51	0.00	0.03
15-30	0.00	0.00	0.00	0.13	0.00	0.00	0.15	0.00	0.00	0.07	0.00	0.00	0.14	0.00	0.00
30-45	0.00	0.00	0.00	0.13	0.03	0.01	0.08	0.00	0.00	0.12	0.00	0.00	0.13	0.03	0.01
45-60	0.00	0.00	0.00	0.13	0.00	0.00	0.01	0.00	0.00	0.04	4.04	0.00	0.13	0.00	0.00
60-75	0.01	0.00	0.00	0.07	0.01	0.00	0.00	0.00	0.00	0.12	0.10	0.00	0.12	0.01	0.00
75-90	0.00	0.00	0.00	0.11	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.11	0.00	0.00
90-105	0.00	0.00	0.00	0.02	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00
105-120	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.01	0.00	0.00
	Gleysols (n=2)														
LFH	0.44	0.00	0.00	0.04	0.00	0.08	1.34	0.00	0.00	0.34	0.00	0.00	0.59	0.00	0.08
0-15	0.04	0.00	0.00	0.16	0.02	0.00	0.19	0.00	0.00	0.05	0.00	0.00	0.37	0.02	0.00
15-30	0.03	0.00	0.00	0.12	0.00	0.00	0.16	0.00	0.00	0.59	0.00	0.00	0.57	0.00	0.00
30-45	0.01	0.00	0.00	0.12	0.00	0.00	0.11	0.00	0.00	0.10	0.00	0.00	0.12	0.00	0.00
45-60	0.01	0.00	0.00	0.09	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.10	0.00	0.00
60-75	0.00	0.00	0.00	0.21	0.02	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.18	0.02	0.00
75-94	0.00	0.00	0.00	0.27	0.00	0.00	0.01	0.00	0.00	0.02	0.00	0.00	0.24	0.00	0.00
90-1015	0.00	0.00	0.00	0.07	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.00	0.09	0.00	0.00
105-120	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Luvisols (n=11)														
LFH	0.51	0.07	0.00	4.26	0.02	0.05	0.77	0.00	0.00	0.82	0.00	0.00	4.70	0.07	0.05
0-15	0.12	0.01	0.00	0.25	0.02	0.03	0.23	0.00	0.00	0.11	0.00	0.00	0.37	0.02	0.03
15-30	0.03	0.01	0.00	0.12	0.01	0.02	0.11	0.00	0.00	0.06	0.00	0.00	0.20	0.01	0.02
3045	0.01	0.00	0.00	0.12	0.01	0.02	0.06	0.00	0.00	0.04	0.00	0.00	0.15	0.00	0.02
45-60	0.01	0.00	0.00	0.10	0.01	0.02	0.04	0.00	0.00	0.02	0.00	0.00	0.10	0.01	0.02
60-75	0.09	0.01	0.00	0.06	0.01	0.00	0.02	0.00	0.00	0.05	0.00	0.00	0.11	0.02	0.00
75-90	0.01	0.00	0.00	0.07	0.00	0.01	0.01	0.00	0.00	0.03	0.00	0.00	0.09	0.00	0.01
94-105	0.03	0.00	0.00	0.04	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.05	0.00	0.00
105-120	0.02	0.00	0.00	0.04	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.04	0.04	0.00

Table 1b.
Root length distribution (C.V. %) in boreal forest soils

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 4	---------- Root length (C.V.) 6-year-old (n=7) ----------														
0-3 (LFH)	73.9	0.0	0.0	107.9	264.5	0.0	129.1	264.6	0.0	80.8	147.3	0.0	111.4	101.4	0.0
0-15	83.2	0.0	0.0	120.6	172.7	0.0	83.8	264.6	0.0	95.0	178.1	264.6	68.7	104.7	264.6
15-30	124.0	0.0	0.0	99.6	212.4	0.0	143.4	0.0	0.0	67.2	0.0	0.0	128.8	212.4	0.0
30-45	142.3	0.0	0.0	81.9	264.6	0.0	187.8	0.0	0.0	76.7	0.0	0.0	174.1	264.6	0.0
45-60	114.1	0.0	0.0	118.4	0.0	0.0	144.5	0.0	0.0	70.5	0.0	0.0	124.2	0.0	0.0
60-75	105.8	264.5	0.0	170.2	0.0	0.0	180.8	0.0	0.0	51.6	0.0	0.0	100.0	264.6	0.0
75-90	116.5	0.0	0.0	162.4	0.0	0.0	132.5	0.0	0.0	103.6	0.0	0.0	89.9	0.0	0.0
90-105	129.9	0.0	0.0	183.7	0.0	0.0	217.4	0.0	0.0	140.4	0.0	0.0	167.6	0.0	0.0
105-120	264.5	0.0	0.0	217.5	0.0	0.0	264.6	0.0	0.0	178.4	0.0	0.0	151.4	0.0	0.0
Site 1	---------- Root length (C.V.) 10-year-old (n=7) ----------														
0-4 (LFH)	44.9	264.6	0.0	59.3	221.3	0.0	97.9	0.0	0.0	65.3	101.1	0.0	81.3	101.8	0.0
0-15	52.0	264.6	0.0	61.2	69.6	264.6	116.4	0.0	0.0	29.0	264.6	0.0	102.1	64.6	264.6
15-30	119.2	171.5	0.0	60.8	194.0	0.0	104.5	0.0	0.0	61.5	0.0	0.0	80.7	168.6	0.0
30-45	145.1	0.0	264.6	45.3	0.0	0.0	86.4	0.0	0.0	54.4	0.0	0.0	69.0	0.0	264.6
45-60	170.8	0.0	0.0	45.5	0.0	0.0	76.6	0.0	0.0	58.4	0.0	0.0	42.3	0.0	0.0
60-75	97.0	264.6	264.6	68.9	0.0	0.0	85.2	0.0	0.0	55.8	0.0	0.0	35.8	264.6	264.6
75-90	112.2	264.6	0.0	43.9	0.0	0.0	103.4	0.0	0.0	28.9	0.0	0.0	63.1	264.6	0.0
90-105	185.6	0.0	0.0	74.3	0.0	0.0	120.3	0.0	0.0	56.3	0.0	0.0	72.2	0.0	0.0
105-120	174.0	0.0	0.0	80.3	0.0	0.0	118.3	0.0	0.0	54.6	0.0	0.0	86.3	0.0	0.0
Site 2	---------- Root length (C.V.) 20-year-old (n=7) ----------														
0-5 (LFH)	47.7	93.1	188.4	89.3	175.7	173.2	163.0	0.0	0.0	28.2	134.3	264.6	113.7	92.6	155.6
0-15	52.5	94.3	264.6	43.0	108.0	264.6	188.6	0.0	0.0	54.5	264.6	0.0	148.8	74.5	264.6
15-30	157.2	264.6	0.0	73.4	264.6	264.6	174.6	0.0	0.0	63.1	0.0	0.0	154.7	176.7	264.6
30-45	57.7	0.0	0.0	98.4	191.5	0.0	188.3	0.0	0.0	85.3	0.0	0.0	171.1	191.5	0.0
45-60	111.2	264.6	0.0	92.0	264.6	0.0	172.4	0.0	0.0	46.6	0.0	0.0	156.5	174.1	0.0
60-75	87.0	0.0	0.0	100.4	171.0	0.0	128.8	0.0	0.0	80.9	264.6	0.0	116.7	124.9	0.0
75-90	99.0	0.0	0.0	155.7	0.0	0.0	104.7	0.0	0.0	55.4	0.0	0.0	90.5	0.0	0.0
90-105	172.3	0.0	0.0	173.2	0.0	0.0	155.7	0.0	0.0	39.1	0.0	0.0	124.8	0.0	0.0
105-120	126.5	0.0	0.0	223.7	0.0	0.0	130.2	0.0	0.0	54.1	0.0	0.0	118.1	0.0	0.0
Site 3	---------- Root length (C.V.) 110-year-old (n=7) ----------														
0-5 (LFH)	90.5	114.9	176.7	43.1	107.5	0.0	164.3	0.0	0.0	100.5	112.4	0.0	84.2	55.6	167.3
0-15	272.3	299.1	0.0	115.3	239.2	0.0	229.1	0.0	0.0	94.0	302.4	0.0	83.0	83.4	0.0
15-30	319.2	0.0	0.0	256.7	661.4	793.7	407.2	0.0	0.0	364.9	0.0	0.0	79.9	247.5	247.5
30-45	432.4	630.7	0.0	295.5	467.5	0.0	447.6	0.0	0.0	158.7	0.0	0.0	56.1	130.9	0.0
45-60	503.5	992.2	0.0	176.0	0.0	0.0	428.3	0.0	0.0	218.3	0.0	0.0	53.0	162.0	0.0
60-75	461.5	458.7	0.0	386.4	661.4	0.0	793.7	0.0	0.0	124.6	661.4	0.0	72.1	138.3	0.0
75-90	273.9	520.9	0.0	258.6	0.0	0.0	793.7	0.0	0.0	194.2	0.0	0.0	66.0	101.5	0.0
90-105	280.4	661.4	0.0	480.0	992.2	0.0	0.0	0.0	0.0	229.5	0.0	0.0	139.2	135.6	0.0
105-120	451.9	793.7	0.0	372.4	0.0	0.0	0.0	0.0	0.0	189.1	0.0	0.0	76.0	247.5	0.0

Table 1b.
Root length distribution (C.V. %) in boreal forest soils (Continued)

Depth	Spruce			Aspen			Grass			Other			Total		
(cm)	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5	<2	2-5	>5
Site 5	---------- Root length (C.V.) 60-year-old ----------														
	Brunisols (n=5)														
LFH	134.1	223.6	0.0	47.2	223.6	223.6	121.4	0.0	0.0	92.0	500.0	0.0	50.4	175.9	223.6
0-15	138.7	0.0	0.0	62.5	0.0	223.6	91.1	0.0	0.0	134.7	0.0	0.0	54.2	0.0	223.6
15-30	0.0	0.0	0.0	47.3	0.0	0.0	116.9	0.0	0.0	126.8	0.0	0.0	30.2	0.0	0.0
30-45	0.0	0.0	0.0	114.3	223.6	223.6	223.6	0.0	0.0	145.2	0.0	0.0	54.3	223.6	223.6
45-60	0.0	0.0	0.0	136.7	0.0	0.0	223.6	0.0	0.0	87.8	0.0	0.0	94.7	0.0	0.0
60-75	223.6	0.0	0.0	82.0	223.6	0.0	0.0	0.0	0.0	189.7	0.0	0.0	76.1	223.6	0.0
75-90	0.0	0.0	0.0	181.4	0.0	0.0	0.0	0.0	0.0	178.4	0.0	0.0	171.2	0.0	0.0
90-105	0.0	0.0	0.0	125.7	0.0	0.0	0.0	0.0	0.0	223.6	0.0	0.0	130.8	0.0	0.0
105-120	0.0	0.0	0.0	223.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	223.6	0.0	0.0
	Gleysols (n=2)														
LFH	141.4	0.0	0.0	1.7	0.0	141.4	141.4	0.0	0.0	45.9	0.0	0.0	14.2	0.0	141.4
0-15	141.4	0.0	0.0	30.9	141.4	0.0	141.4	0.0	0.0	30.4	0.0	0.0	42.9	141.4	0.0
15-30	141.4	0.0	0.0	109.0	0.0	0.0	141.4	0.0	0.0	112.4	0.0	0.0	74.1	0.0	0.0
30-45	141.4	0.0	0.0	118.0	0.0	0.0	141.4	0.0	0.0	141.4	0.0	0.0	49.0	0.0	0.0
45-60	141.4	0.0	0.0	130.4	0.0	0.0	141.4	0.0	0.0	141.4	0.0	0.0	106.7	0.0	0.0
60-75	0.0	0.0	0.0	103.0	141A	0.0	141.4	0.0	0.0	82.2	0.0	0.0	75.8	141.4	0.0
75-90	0.0	0.0	0.0	104.8	0.0	0.0	141.4	0.0	0.0	141.4	0.0	0.0	85.3	0.0	0.0
90-105	0.0	0.0	0.0	71.1	0.0	0.0	0.0	0.0	0.0	90.0	0.0	0.0	73.9	0.0	0.0
105-120	0.0	0.0	0.0	10.5	0.0	0.0	141.4	0.0	0.0	0.0	0.0	0.0	5.7	0.0	0.0
	Luvisols (n=11)														
LFH	93.2	237.4	0.0	71.3	331.7	331.7	100.8	0.0	0.0	71.3	0.0	0.0	55.7	192.8	317.5
0-15	157.7	236.8	0.0	57.4	260.0	149.5	147.6	0.0	0.0	100.5	331.7	0.0	48.6	148.5	145.4
15-30	255.0	331.7	0.0	58.3	223.5	242.4	217.4	0.0	0.0	171.9	0.0	0.0	64.6	175.2	232.9
30-45	283.5	0.0	0.0	87.2	331.7	255.1	270.9	0.0	0.0	143.4	0.0	0.0	75.7	317.5	245.0
45-60	269.0	0.0	0.0	86.0	222.5	331.7	273.2	0.0	0.0	119.7	0.0	0.0	62.3	214.1	317.5
60-75	228.9	331.7	0.0	70.5	240.5	0.0	331.7	0.0	0.0	179.3	0.0	0.0	71.5	266.5	0.0
75-90	223.3	0.0	0.0	101.5	0.0	331.7	331.7	0.0	0.0	198.5	0.0	0.0	56.6	0.0	317.5
90-105	225.5	0.0	0.0	101.2	0.0	0.0	331.7	0.0	0.0	239.5	0.0	0.0	83.2	0.0	0.0
105-120	331.7	0.0	0.0	149.4	0.0	0.0	331.7	0.0	0.11	331.7	0.0	0.0	119.8	0.0	0.0

APPENDIX D
Root Weight Distributions by Depth Increment and Species

Table 3.
Root weight distribution in boreal forest soils

Depth (cm)	Spruce	Aspen	Grass	Other	Total
Luvisols	---------- Root weight (mg/cm^3) 6-year-old (n=7) ----------				
0-3 (LFH)	0.2643	0.9214	0.7176	3.3250	5.2283
3-15	0.0666	0.4738	2.5392	0.1884	3.2680
15-30	0.0051	0.2391	0.0310	0.0683	0.3435
30-45	0.0011	0.0827	0.0117	0.0336	0.1292
45-60	0.0038	0.0336	0.0130	0.0575	0.1079
60-75	0.0259	0.0245	0.0031	0.0330	0.0865
75-90	0.0024	0.0188	0.0011	0.0192	0.0416
90-105	0.0011	0.0148	0.0013	0.0292	0.0464
105-120	0.0013	0.0074	0.0003	0.0130	0.0220
Luvisols	---------- Root weight (mg/cm^3) 10-year-old (n=7) ----------				
0-4 (LFH)	0.5936	2.5633	0.6357	4.9837	8.7773
4-15	0.2768	2.8508	0.2248	0.7213	4.0737
15-30	0.0557	0.2453	0.0362	0.1604	0.4986
30-45	0.1401	0.0114	0.0102	0.1010	0.2627
45-60	0.0154	0.0144	0.0074	0.0333	0.1304
60-75	0.2662	0.0154	0.0061	0.1067	0.3943
75-90	0.0317	0.0133	0.0045	0.0524	0.1118
90-105	0.0116	0.0042	0.0017	0.0385	0.0559
105-120	0.0068	0.0045	0.0032	0.0286	0.0432
Luvisols	---------- Root weight (mg/cm^3) 20-year-old (n=7) ----------				
0-5 (LFH)	3.7869	4.5267	0.7033	10.1027	19.1196
5-15	1.8223	2.4250	0.2253	1.0771	5.5496
15-30	0.2045	0.7435	0.0840	0.2301	1.2621
30-45	0.0157	0.2152	0.0675	0.2919	0.5903
45-60	0.0375	0.1471	0.0409	0.1376	0.3632
60-75	0.0044	0.1786	0.0254	0.2017	0.4100
75-90	0.0049	0.0193	0.0159	0.0929	0.1331
90-105	0.0023	0.0036	0.0068	0.0542	0.0669
105-120	0.0015	0.0059	0.0057	0.0186	0.0317
Luvisols	---------- Root weight (mg/cm^3) 110-year-old (n=7) ----------				
0-5 (LFH)	4.8972	3.3169	0.1688	3.1577	11.5406
5-15	0.5903	1.2256	0.0510	0.4509	2.3177
15-30	0.0296	0.4751	0.0047	0.1035	0.6129
30-45	0.2599	0.6737	0.0008	0.0518	0.9861
45-60	0.1077	0.2034	0.0009	0.0480	0.3600
60-75	0.1735	0.2210	0.0015	0.0765	0.4725
75-90	0.4358	0.0959	0.0006	0.0381	0.5704
90-105	0.0669	0.1276	0.0000	0.0191	0.2136
105-120	0.0936	0.0091	0.0000	0.0138	0.1166

Table 3.
Root weight distribution in boreal forest soils (Continued)

Depth (cm)	Spruce	Aspen	Grass	Other	Total
	---------- Root weight (mg/cm^3) 60-year-old ----------				
			Brunisols (n=5)		
0-6 (LFH)	0.8656	4.3192	0.6130	3.9502	9.7479
6-15	0.0129	2.7364	0.0829	4.8992	7.7314
15-30	0.0738	0.1919	0.0146	0.0794	0.3596
30-45	0.0000	1.1240	0.0223	0.0271	1.1734
45-60	0.0000	0.3041	0.0003	0.0141	0.3185
60-75	0.0316	0.1348	0.0101	0.0140	0.1905
75-90	0.0000	0.0114	0.0000	0.0008	0.0122
90-105	0.0000	0.0024	0.0000	0.0000	0.0024
105-120	0.0000	0.0029	0.0000	0.0000	0.0029
			Gleysols (n=2)		
0-9 (LFH)	0.1354	10.2736	0.2996	2.2174	12.9259
9-15	0.0173	1.9904	0.0166	0.4087	2.4330
15-30	0.0668	0.5157	0.0544	0.3202	0.9572
30-45	0.0027	1.4459	0.0345	0.1606	1.6437
45-60	0.0053	0.2092	0.0181	0.2216	0.4543
60-75	0.0000	0.4733	0.0115	0.2893	0.7741
75-90	0.0000	0.3645	0.0049	0.0305	0.3999
90-105	0.0000	0.2826	0.0123	0.0566	0.3516
105-120	0.0000	0.1800	0.0195	0.1247	0.3242
			Luvisols (n=11)		
0-4 (LFH)	2.0273	5.7381	0.5088	1.1227	9.3970
4-15	1.4739	4.6192	0.0414	0.0681	6.2026
15-30	0.1221	2.7557	0.0134	0.0164	2.9076
30-45	0.0174	0.7114	0.0084	0.0092	0.7464
45-60	0.0043	1.5123	0.0046	0.0205	1.5417
60-75	0.1863	0.3077	0.0022	0.0123	0.5085
75-90	0.0104	0.4570	0.0019	0.0059	0.4752
90-105	0.0268	0.0312	0.0005	0.0007	0.0592
105-120	0.0074	0.0179	0.0006	0.0034	0.0293

Table 3a.
Root weight distribution (Mean, Standard deviation and C.V. %)
in boreal forest soils

Depth	Spruce			Aspen			Grass			Other			
(cm)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Total
Luvisols	---------- Root length (cm/cm^3) 6-year-old (n=7) ----------												
LFH	0.268	0.26	95	0.828	1.02	123	1.598	2.49	156	3.115	3.26	105	5.809
0-15	0.079	0.08	103	0.433	0.53	122	2.184	5.55	254	1.079	2.38	220	3.775
15-30	0.010	0.02	169	0.249	0.42	167	0.044	0.05	124	0.074	0.04	52	0.378
311-45	0.004	0.01	133	0.078	0.09	118	0.042	0.08	192	0.037	0.04	105	0.161
45-60	0.008	0.01	157	0.036	0.03	89	0.026	0.04	144	0.049	0.04	81	0.120
60-75	0.003	0.01	157	0.020	0.04	191	0.003	0.00	166	0.029	0.02	75	0.055
75-90	0.022	0.05	246	0.017	0.03	163	0.002	0.00	120	0.018	0.02	116	0.059
90-105	0.003	0.00	126	0.013	0.03	218	0.001	0.00	183	0.027	0.03	129	0.044
105-120	0.001	0.00	265	0.005	0.01	254	0.000	0.00	265	0.011	0.02	228	0.017
Luvisols	---------- Root length (cm/cm^3) 10-year-old (n=7) ----------												
LFH	0.594	0.33	55	2.563	4.22	165	0.637	0.63	98	4.984	3.82	77	8.777
0-15	0.277	0.23	82	2.851	5.12	179	0.225	0.26	117	0.721	0.61	85	4.074
15-30	0.057	0.06	111	0.245	0.30	123	0.036	0.04	108	0.160	0.08	51	0.499
30-45	0.140	0.35	247	0.011	0.01	47	0.010	0.01	92	0.101	0.08	78	0.263
45-60	0.015	0.03	171	0.014	0.01	57	0.007	0.01	83	0.093	0.08	83	0.130
60-75	0.266	0.59	221	0.015	0.01	70	0.006	0.01	95	0.107	0.08	71	0.394
75-90	0.032	0.04	136	0.013	0.01	107	0.005	0.01	114	0.062	0.02	37	0.112
90-105	0.012	0.03	235	0.004	0.00	59	0.002	0.00	140	0.038	0.03	83	0.056
105-120	0.007	0.01	169	0.005	0.00	98	0.003	0.00	128	0.029	0.03	104	0.043
Luvisols	---------- Root length (cm/cm^3) 20-year-old (n=7) ----------												
LFH	3.787	3.26	86	4.527	3.85	85	0.703	1.08	154	10.103	11.31	112	19.120
0-15	1.822	1.36	74	2.425	3.31	136	0.225	0.31	136	1.077	0.72	67	5.550
15-30	0.205	0.47	230	0.743	1.42	191	0.084	0.15	175	0.230	0.10	42	1.262
30-45	0.016	0.01	92	0.215	0.29	134	0.067	0.13	190	0.292	0.27	92	0.590
45-60	0.038	0.08	225	0.147	0.18	120	0.041	0.07	174	0.138	0.06	45	0.363
60-75	0.004	0.01	129	0.179	0.23	127	0.025	0.03	135	0.202	0.13	67	0.410
75-90	0.005	0.00	98	0.019	0.04	194	0.016	0.02	106	0.093	0.08	86	0.133
90-105	0.002	0.00	174	0.004	0.01	174	0.007	0.01	160	0.054	0.03	60	0.067
105-120	0.002	0.00	128	0.006	0.01	255	0.005	0.01	131	0.019	0.01	58	0.032
Luvisols	---------- Root length (cm/cm^3) 110-year-old (n=7) ----------												
LFH	4.897	3.56	73	3.317	2.70	82	0.169	0.26	152	3.158	1.71	54	11.541
0-15	0.590	0.44	74	1.226	0.87	71	0.051	0.07	128	0.451	0.22	49	2.318
15-30	0.030	0.04	136	0.475	0.45	96	0.005	0.01	150	0.104	0.10	95	0.613
30-45	0.260	0.40	154	0.674	1.27	188	0.001	0.00	162	0.052	0.04	77	0.986
45-60	0.108	0.18	170	0.203	0.15	73	0.001	0.00	166	0.048	0.05	99	0.360
60-75	0.173	0.19	108	0.221	0.30	136	0.002	0.00	247	0.076	0.07	95	0.472
75-90	0.435	0.48	110	0.096	0.08	85	0.001	0.00	247	0.038	0.04	95	0.570
90-105	0.067	0.11	158	0.128	0.19	151	0.000	0.00	0	0.019	0.01	78	0.214
105-120	0.094	0.20	218	0.009	0.01	89	0.000	0.00	0	0.014	0.01	92	0.117

Table 3a.
Root weight distribution (Mean, Standard deviation and C.V. %)
in boreal forest soils (Continued)

Depth	Spruce			Aspen			Grass			Other			
(cm)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Mean	Stdev	CV(%)	Total
	---------- Root length (cm/cm^3) 6-year-old ----------												
	Brunisols (n=5)												
LFH	0.866	1.19	138	4.319	2.10	49	0.613	0.68	110	3.950	6.93	175	9.748
0-15	0.013	0.02	153	2.736	3.89	142	0.083	0.10	122	4.899	10.92	223	7.731
15-30	0.074	0.16	224	0.192	0.15	78	0.015	0.02	147	0.079	0.06	70	0.360
30-45	0.000	0.00	0	1.124	1.67	148	0.022	0.03	138	0.027	0.02	76	1.173
45-60	0.000	0.00	0	0.304	0.47	154	0.000	0.00	224	0.014	0.01	92	0.318
60-75	0.032	0.07	224	0.135	0.13	99	0.010	0.02	224	0.014	0.02	147	0.190
75-90	0.000	0.00	0	0.011	0.01	129	0.000	0.00	0	0.001	0.00	149	0.012
90-105	0.000	0.00	0	0.002	0.00	194	0.000	0.00	0	0.000	0.00	0	0.002
105-120	0.000	0.00	0	0.003	0.01	224	0.000	0.00	0	0.000	0.00	0	0.003
	Gleysols (n=2)												
LFH	0.135	0.23	173	10.274	12.29	120	0.300	0.28	94	2.217	1.58	71	12.926
0-15	0.017	0.03	173	1.990	1.01	51	0.017	0.03	173	0.409	0.52	127	2.433
15-30	0.067	0.12	173	0.516	0.72	140	0.054	0.05	95	0.320	0.27	84	0.957
30-45	0.003	0.00	173	1.446	2.04	141	0.035	0.05	144	0.161	0.23	146	1.644
45-60	0.005	0.01	173	0.209	0.23	110	0.018	0.03	161	0.222	0.38	170	0.454
60-75	0.000	0.00	0	0.473	0.71	150	0.012	0.02	154	0.289	0.40	137	0.774
75-90	0.000	0.00	0	0.364	0.50	137	0.005	0.01	129	0.031	0.03	89	0.400
90-105	0.000	0.00	0	0.283	0.34	119	0.012	0.02	166	0.057	0.09	163	0.352
105-120	0.000	0.00	0	0.180	029	159	0.019	0.03	162	0.125	0.22	173	0.324
	Luvisols (n=11)												
LFH	2.027	4.29	212	5.738	6.36	111	0.509	0.53	105	1.123	0.66	59	9.397
0-15	1.474	3.42	232	4.619	6.45	140	0.041	0.06	153	0.068	0.08	117	6.203
15-30	0.122	0.33	274	2.756	5.17	188	0.013	0.03	210	0.016	0.03	168	2.908
30-45	0.017	0.04	254	0.711	0.94	132	0.008	0.02	197	0.009	0.01	119	0.746
45-60	0.004	0.01	303	1.512	3.46	228	0.005	0.01	295	0.021	0.04	205	1.542
60-75	0.186	0.61	329	0.308	0.31	100	0.002	0.01	332	0.012	0.02	188	0.508
75-90	0.010	0.02	187	0.457	1.27	278	0.002	0.01	332	0.006	0.01	231	0.475
90-105	0.027	0.07	251	0.031	0.03	98	0.000	0.00	259	0.001	0.00	320	0.059
105-120	0.007	0.02	332	0.018	0.02	119	0.001	0.00	332	0.003	0.01	332	0.029