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Soil displacement and compaction effects on conifer seedlings in Southeast British Columbia: Study establishment

D.G. Maynard, K. E. Hogg, E.F. Wass, and M.P. Curran

Canada

The Pacific Forestry Centre, Victoria, British Columbia

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This study began as part of a larger co-operative research project between Natural Resources Canada, Canadian Forest Service (CFS) and the British Columbia Ministry of Forests, Nelson Region entitled "Tree growth and nutrition in calcareous soils."

Abstract

Soil disturbance from forest harvesting has been shown to compromise site productivity. We established satellite trials in five of the Long-Term Soil Productivity (LTSP) sites in southeast British Columbia between 1999 and 2003. The objective of these trials was to determine the effects of soil compaction and displacement on tree growth on smaller plots than those in the LTSP. Eight treatments of various combinations of compaction and displacement were included at each of the five LTSP sites: undisturbed, no compaction; undisturbed, light compaction; undisturbed, heavy compaction; shallow gouge, no compaction; shallow gouge, light compaction; deep gouge, no compaction; deep gouge, light compaction; and deposit, no compaction. Each treatment was replicated a minimum of 20 times at each site in most cases. Plots were 1.5 m x 1.5 m with at least 1.5 m between plots. Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) was planted at all five sites; lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) at the three sites in the East Kootenays (Mud Creek, Emily Creek, and Kootenay East); and western white pine (*Pinus monticola* Dougl.) at the two sites in the West Kootenays (Rover Creek and McPhee Creek). Tree growth, soil physical and chemical properties, and microclimate data will be measured at varying intervals during the first 10 years following planting. This report describes study establishment and presents some initial background data.

Keywords: soil disturbance, long-term soil productivity, compaction, calcareous soils, organic matter.

Resume

Il a été démontré que la perturbation des sols causée par l'exploitation forestière nuit à la productivité des sites. De 1999 à 2004, nous avons effectué des essais complémentaires dans cinq sites du projet « Productivité à long terme du sol » (PLTS) dans le sud-est de la Colombie-Britannique. Ces essais avaient pour but de déterminer les effets du compactage et du déplacement des sols sur le taux de croissance des arbres dans des parcelles plus petites que celles des sites du projet PLTS. Huit différentes combinaisons de compactage et de déplacement ont été appliquées dans les cinq sites du projet PLTS : sol non perturbé et non compacté; sol non perturbé et peu compacté; sol non perturbé et très compacté; entailles peu profondes et sol non compacté; entailles peu profondes et sol peu compacté; entailles profondes et sol non compacté; entailles profondes et sol peu compacté; dépôt avec sol non compacté. Chaque combinaison a été répétée au moins 20 fois dans chacun des sites. Les parcelles mesuraient 1,5 m sur 1,5 m et l'espacement minimum entre elles était de 1,5 m. Le douglas taxifolié (*Pseudotsuga menziesii* var. *menziesii* Dougl.) a été planté dans les cinq sites, le pin tordu latifolié (*Pinus contorta* var. *latifolia*) dans les trois sites de Kootenay Est (Mud Creek, Emily Creek et Kootenay Est) et le pin argenté (*Pinus monticola* Dougl.) dans les deux sites de Kootenay Ouest (Rover Creek et McPhee Creek). Le taux de croissance des arbres, les propriétés physiques et chimiques des sols ainsi que les données sur le microclimat ont été mesurées selon divers intervalles durant les dix premières années suivant la plantation. Ce rapport décrit les étapes d'établissement du projet et présente les données initiales et le contexte du projet.

Mots-clés : perturbation du sol, productivité à long terme du sol, compactage du sol, sol calcaire, matière organique

1. Introduction

The effects of disturbance from forestry operations on soil productivity have been an important issue in British Columbia (BC) and disturbance limits are applied to permanent access (e.g., road network) and areas to be reforested (Curran and Maynard 2009). Soil disturbance default standards under the *Forest and Range Practices Act* allow up to 5–10% net disturbance (excluding permanent access) within a cutblock (see Curran et al. 2007 for further details). The Long-Term Soil Productivity study (LTSP) is an international project designed to investigate effects of soil compaction and organic matter retention on forest productivity over the long term (Powers and Avers 1995). The BC Ministry of Forests (now BC Ministry of Forests, Lands and Natural Resource Operations) established a series of LTSP studies in British Columbia in the 1990s in co-operation with the USDA Forest Service (Holcomb 1996). Currently there are 14 installations in British Columbia covering four biogeoclimatic zones. The latest installations included three in the Interior Douglas-fir (IDF) biogeoclimatic zone on calcareous (high pH) soils and two in the Interior Cedar–Hemlock (ICH) biogeoclimatic zone in southeast BC (Figure 1). This report describes the establishment of satellite research trials adjacent to these five sites.

The LTSP treatments were selected to cover a range of compaction and organic matter retention from minimal to extreme. The plot sizes were 40 m x 70 m, therefore, roots of the seedlings would be entirely within the plots in the disturbed areas. The satellite trials were established to complement the LTSP trials by evaluating another potentially important disturbance class: soil displacement (gouges and deposits) as well as compaction. Additionally, in these trials plot size (1.5 m x 1.5 m) emulated disturbances that are more likely to be encountered in a cutblock. Thus, it was expected that the seedling roots would extend into the soil outside the disturbed area. Our results will reflect seedling growth for similar disturbances (i.e., gouges or compaction) to those studied at the LTSP sites, but where only part of the soil the roots are growing in has been disturbed.

The three LTSP sites where our IDF satellite research trials (Mud Creek, Kootenay East, and Emily Creek) were established are in the former Invermere Enhanced Forest Management Pilot Project (EFMPP) area of southeast British Columbia.[1] The soils of this area are predominantly calcareous (~80%). The depth to calcareous material varies from a few centimetres to >100 cm. Calcareous soils are rich in calcium (Ca) and are characterized by the presence of free Ca and magnesium (Mg) carbonates and pH values > 7.0.

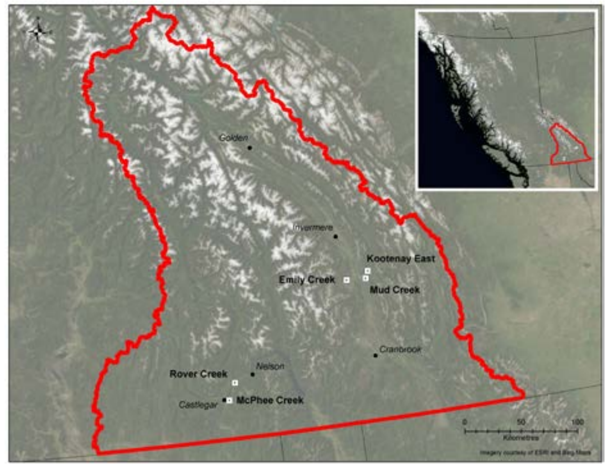
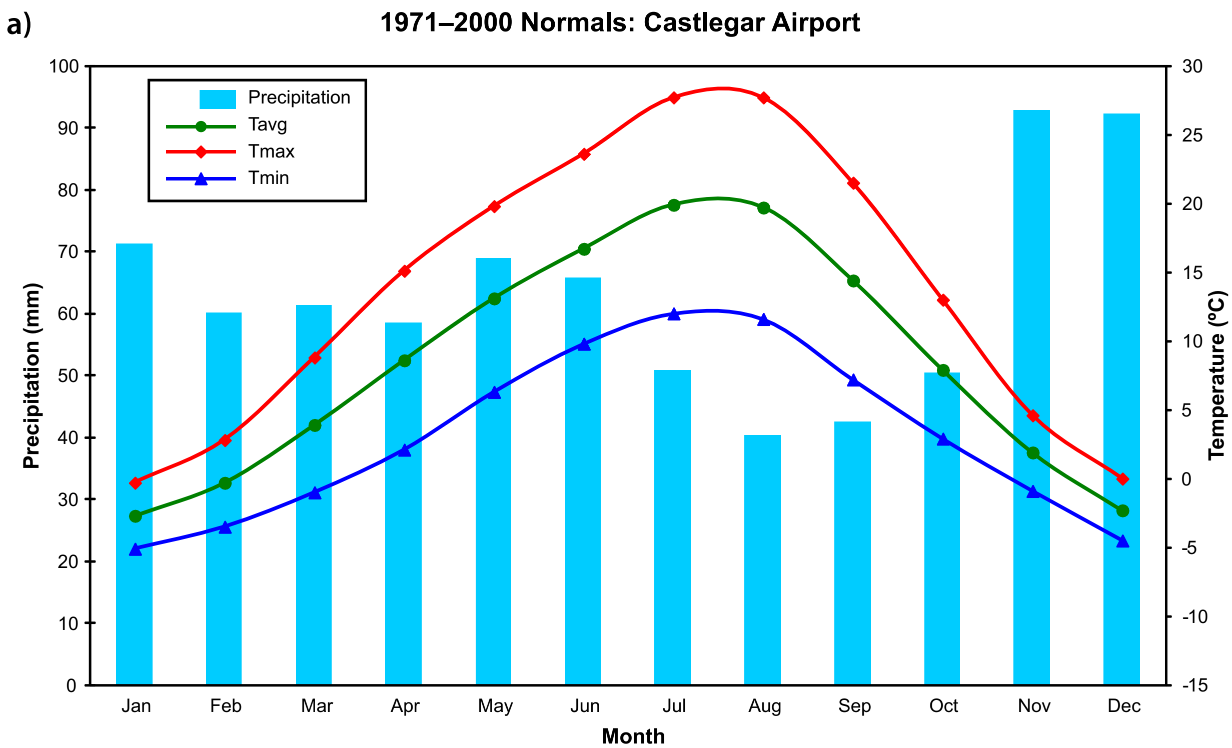


Figure 1. Location of study sites.

Disturbance of calcareous soils (either natural or as a result of forestry operations) can result in the exposure of unweathered subsoils or the mixing of calcareous subsoil with more acidic surface horizons. This may alter the fragile, shallow, mainly acidic topsoil layer from its undisturbed state, thereby affecting the soil's ability to sustain forest productivity (Kishchuk et al. 1999). The presence of carbonates and high pH influences chemical processes and nutrient availability. Deficiencies of several nutrients including iron (Fe), phosphorus (P), manganese (Mn), and zinc (Zn) have been found in tree species on calcareous soils (Kishchuk 2000). Other nutrients, such as nitrogen (N), Ca, and possibly Mg (depending on the parent material) may be more available in calcareous soils. Calcareous soils tend to be fine textured and thus more susceptible to compaction in clayey soils and to erosion in silty soils (Kishchuk et al. 1999). The cementing action of the lime-rich calcareous materials may result in physical limitations such as high bulk density and low macroporosity (Kishchuk 2000).

The soils of the two satellite trials associated with the ICH sites (Rover Creek and McPhee Creek) are in the same soil order as those at the IDF sites (Brunisols, Soil Classification Working Group 1998); however, they developed in non-calcareous parent material, are acidic throughout the profile, and are subject to higher amounts of precipitation (Figures 2a; 2b). Therefore, nutrient limitations and changes to various processes associated with the disturbance of these soils may be different than those associated with the calcareous soils.

[1] The Invermere Enhanced Forest Management Pilot Project was established in 1996. Initial funding (1998–2001) for this work was provided in part by this program.



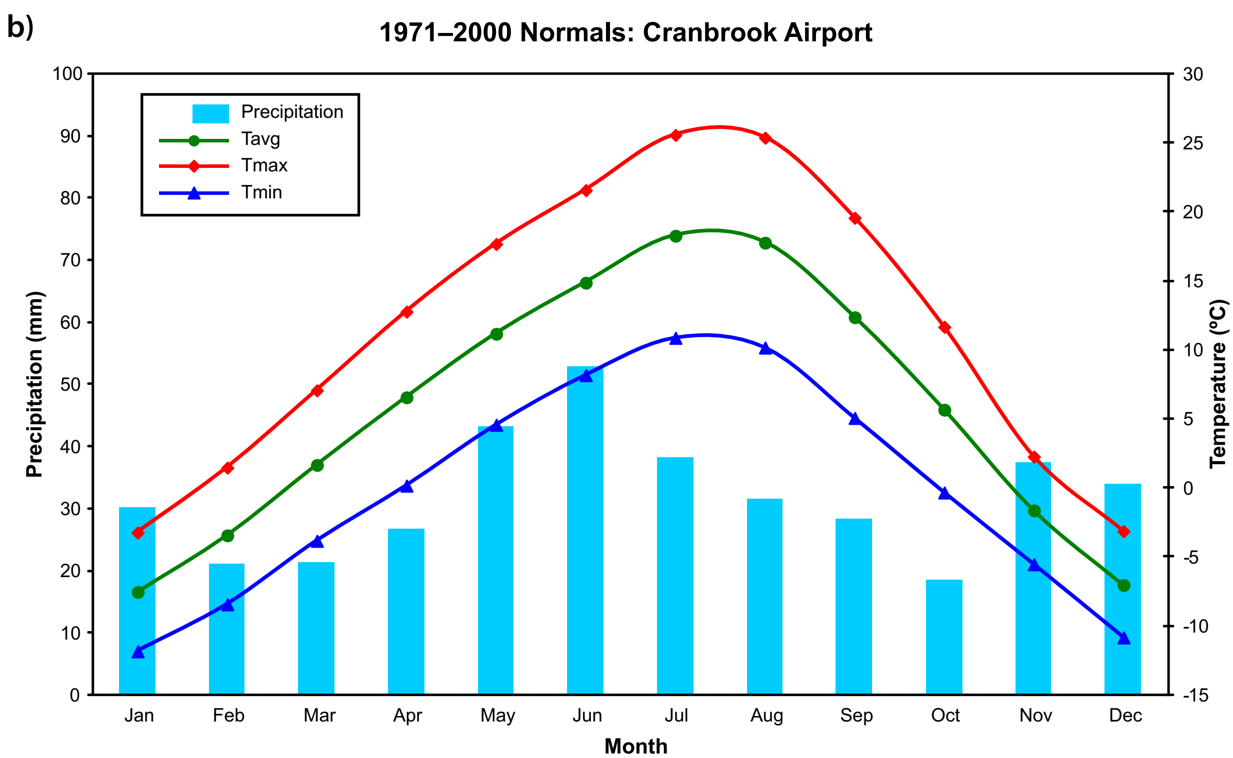


Figure 2. Climatogram of 1971–2000 precipitation and temperature normals at a) Castlegar Airport and b) Cranbrook Airport.

The broad objectives of this study were to investigate and determine how soil compaction and displacement affect forest productivity in the long term and to gain an understanding of the chemical and physical processes controlling productivity in these soils and how they may be affected by disturbances.

The specific objectives of this study were:

i) to determine the effect of compaction and different depths of soil displacement (gouge and deposit) on nutrient dynamics and soil physical properties as it relates to the growth of Douglas-fir (*Pseudotsuga menziesii* var. *menziesii*) and lodgepole pine (*Pinus contorta* var. *latifolia* Dougl.) or western white pine (*Pinus monticola* Dougl.) seedlings,

ii) to compare the growth of Douglas-fir and lodgepole pine (or western white pine) in small microplots (1.5 m X 1.5 m) with the growth reported in similarly treated, but larger (40 m x 70 m) LTSP plots, and

iii) to determine the sensitivity (physical and chemical) of calcareous soils to compaction and displacement.

2. Study Areas

The five LTSP study sites are located in the Kootenay/Boundary Region (British Columbia Ministry of Forests, Lands and Natural Resource Operations) in the southeast corner of British Columbia (Table 1). Mud Creek and Kootenay East are on the eastern side of the Rocky Mountain Trench and Emily Creek is located on the western side. Rover Creek and McPhee Creek were added after the original working plan was in place and are southwest of Nelson, BC (Figure 1). Site characteristics, plot layout, and other background information can be found in Appendices 1 (Mud Creek), 2 (Emily Creek), 3 (Kootenay East), 4 (Rover Creek), and 5 (McPhee Creek).

2.1 Historical Climatic Data

Using climate data from the Cranbrook and Castlegar airports (Environment Canada National Climate Data and Information Archive; 1971–2000), climatographs were created to illustrate precipitation and temperature norms. Cranbrook Airport is closest to the Mud Creek, Emily Creek, and Kootenay East sites and Castlegar Airport is nearest to Rover Creek and McPhee Creek. The airport climate graphics provide some insight on the temperatures and levels of precipitation the research sites might experience. Of note is the difference in the timing of the wet and dry periods: Cranbrook (Figure 2a) has two drier periods (late winter/early spring and late summer/early fall) and is significantly drier overall than Castlegar (Figure 2b). Castlegar has a drier period from July through September. Cranbrook tends to have slightly cooler maxima and minima air temperatures than Castlegar.

Table 1. Study site location details.

Study Site	Location	Elevation (m)	Biogeoclimatic Zone	Establishment Date
Mud Creek (MC)	50º 08"N 115º 44"W	1005	IDFdm2	October 1999
Emily Creek (EC)	50º 09"N 115º 59"W	1180	IDFdm2	September 2000
Kootenay East (KE)	50º 11"N 115º 42"W	1030	IDFdm2	October 2001
Rover Creek (RC)	49º 26"N 117º 30"W	625	ICHdw1	September 2002
McPhee Creek (MP)	49º 18"N 117º 35"W	855	ICHdw1	October 2003

3. Materials and Methods

3.1 Treatments

Figure 3. Photos of a) undisturbed plots, and displacement treatments b) shallow gouge, c) deep gouge, and d) deposit.

The experiment is a completely randomized design with eight treatments (four are shown in Figures 3a–3d). The treatments include: undisturbed, no compaction (UNNC), undisturbed, light compaction (UNLC), undisturbed, heavy compaction (UNHC), shallow gouge, no compaction (SGNC), shallow gouge, light compaction (SGLC), deep gouge, no compaction (DGNC), deep gouge, light compaction (DGLC), and deposit, no compaction (DENC).

Undisturbed areas (harvested, but free of machine traffic) next to the core LTSP plots were designated for satellite plot establishment (Figure 4a). Plots were 1.5 m x 1.5 m in size (separated by a minimum of 1.5 m) and were marked using spray paint and randomly assigned a treatment (minimum 20 plots per treatment per species).

Soil displacement treatments were applied within each painted square using an excavator and a 1.5 m wide bucket (Figure 4b). Compaction was done using an excavator with a vibrating plate (Figure 4c). As the plate was half the size of the plot, it was moved once to ensure all of the area within the plot was compacted. At each location, vibration was applied for 5–10 seconds for light compaction and 30 seconds for heavy compaction. Next to both the shallow and deep gouges deposits were created using the displaced soil removed by the excavator and consisted of varying amounts of surface organic material and mineral soil.

After plots were treated they were assessed and, in some cases, reassigned a treatment if gouge depth was found to be in a different category (Table 2). Therefore, there was some variation in the number of replicates (Table 3). Each plot was identified with a numbered metal plot pin and maps were produced that coded for plot number, location, treatment, and tree species planted.

Shallow gouges ranged in depth from 1–31 cm, deep gouges ranged in depth from 16–51cm, and height of deposits ranged from 9–69 cm (Table 2). Maximum gouge depth was deeper at Rover Creek and McPhee Creek because of soil type and operator differences.

Figure 4. Establishment of satellite plots a) outlined in paint and then treated (as applicable) with b) excavation and c) compaction (excavator fitted with vibrating plate).

Table 2. Soil surface disturbance description.

Soil Surface Disturbance	Site	Depth (cm)
Shallow Gouge	MC	2–15
	EC	1–15
	KE	3–15
	RC	5–20
	MP	8–31
Deep Gouge	MC	16–43
	EC	16–34
	KE	16–39
	RC	21–51
	MP	32–53
		Height (cm)
Deposit	MC	12–65
	EC	10–69
	KE	9–58
	RC	17–62
	MP	5–6

MC=Mud Creek; EC=Emily Creek; KE=Kootenay East; RC=Rover Creek; MP=McPhee Creek.

3.2 Planting

Douglas-fir (DF) and pine (lodgepole pine [LP] at Emily Creek, Mud Creek, and Kootenay East; western white pine [WWP] at Rover Creek and McPhee Creek) were randomly assigned to plots. Three one-year-old container-grown seedlings (1+0) of the same species were planted per plot by an experienced contractor (with the exception of Douglas-fir at Emily Creek and Kootenay East in UNHC and DENC where two trees per plot were planted due to limited stock availability). Seedlings were local provenances and standard stock type. The same seedlots for lodgepole pine (43271) and Douglas-fir (2053) were used for the calcareous sites (Mud Creek, Emily Creek, and Kootenay East). Seedlots for western white pine (unknown) and Douglas-fir (unknown) at Rover Creek and McPhee Creek were the same and came from local provenances and were of standard stock type. Seedlings were planted evenly spaced along a diagonal line through the middle of a plot. Extra deposit plots were planted because mortality on the deposits was expected to be higher than in the other treatments. A summary of planted stock measures is found in Appendix 6.

Table 3. Distribution of plots with respect to treatment and planted tree species.

	Mud Creek (2000)		Emily Creek (2001/2002)		Kootenay East (2002)		Rover Creek (2003)		McPhee Creek (2004)	
	Tree Species									
Soil Displacement Treatment	LP	DF	LP	DF	LP	DF	WWP	DF	WWP	DF
UNNC	21	20	20	20	20	21	20	20	25	28
UNLC	20	20	20	20	21	20	18	19	21	24
UNHC	20	20	20	20	20	21	21	19	20	20
SGNC	17	18	21	22	20	22	21	21	22	21
SGLC	17	17	20	20	19	18	17	20	18	16
DGNC	23	24	19	18	21	19	19	18	15	15
DGLC	24	23	20	20	22	23	24	22	21	20
DENC	37	40	24	26	30	32	24	26	22	22

LP=Lodgepole pine; DF=Douglas-fir; WWP=Western White pine.
UNNC=undisturbed, no compaction; UNLC=undisturbed, light compaction; UNHC=undisturbed, heavy compaction; SGNC=shallow gouge, no compaction; SGLC=shallow gouge, light compaction; DGNC=deep gouge, no compaction; DGLC=deep gouge, light compaction; DENC=deposit, no compaction.

One seedling will be removed and above-ground biomass (current and non-current foliage and wood) and nutrients (see nutrient analysis section below for details) measured at the end of the third growing season in select plots. The seedlings will be thinned to two in the remaining plots by the end of the fifth growing season and after the 10-year measurement there will be one tree (at the centre of each plot) remaining after final thinning. The trees removed will be selected at random. In cases where the centre tree died, the tree to remain in the plot will be determined randomly.

All five study areas were fenced to keep out grazing cattle, elk, and deer. Elk fencing was in place at the time of planting at Kootenay East, Rover Creek, and McPhee Creek. However, fencing was delayed 2 years at Mud Creek and 1 year at Emily Creek so, in the interim, seedlings were caged with Vexar® net tubes after planting to protect seedlings from grazing (Figure 5). The cages were removed in 2003 after elk fencing had been installed at the two sites.

At all sites, woody species (e.g., aspen suckers) and advanced regeneration were removed from the entire study area at time of planting with a brush-saw to prevent below-ground and above-ground competition. In addition, within the 1.5 m x 1.5 m plot area, grasses and woody species were clipped yearly for the first 3 years to limit competition. Periodic vegetation control by cutting or clipping will be done as needed until the seedlings are well established (about 5 years).

Figure 5. Seedling covered in Vexar® tubes after planting.

3.3 Microclimate

Two microclimate stations each (Figures 6a; 6b) were installed at Mud Creek (June 2000: Areas A and D), Emily Creek (June 2001: Areas 5 and 15), and Kootenay East (June 2002: Areas B and C), and one station was installed at Rover Creek (June 2007: Area B) and one at McPhee Creek (May 2008: Area B). Data will be used to interpret growth and soil nutrient availability.

The basic microclimate station records the following parameters for each treatment:

- **air temperature** at 20cm (in treatments UNNC, SGLC, DGNC, DGLC, and DENC)

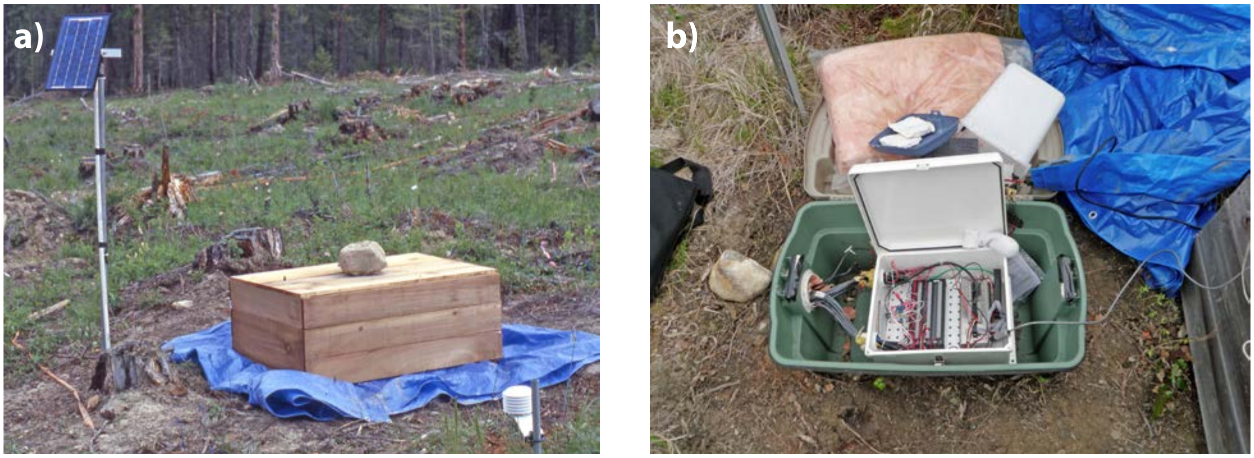


Figure 6. Microclimate station at Mud Creek a) with tarp and cedar box cover waterproof container and b) showing datalogger, multiplexer, and battery in buried waterproof container.

- **soil moisture** (either as soil moisture [%] using GroPoint sensors [E.S.I. Environmental Sensors Inc., Sidney, B.C., Canada] or as soil water potential [CSI 227 Delmhorst cylindrical soil moisture blocks; Campbell Scientific, Edmonton, AB, Canada] at 10 cm depth in UNNC, SGLC, DGNC, DGLC, and DENC
- **soil temperature** at 10 cm depth in UNNC, SGLC, DGLC, DGNC, and DENC
- **soil temperature** at 30 cm depth (UNNC)

More detailed information about treatments and measurements are noted in Appendix 7. Measurements will be taken every 5 minutes and averaged on an hourly basis during the growing season. In the winter (October 1–April 1) only 24-hour means will be recorded. At Mud Creek, Emily Creek, and Rover Creek, BC Ministry of Forests weather stations were installed at central locations within the larger study areas to record air temperature and precipitation.

3.4 Soil Physical Attributes

Bulk densities were determined using the Troxler neutron gauge at Mud Creek and Emily Creek (Figure 7a) and by the sand replacement technique (Figure 7b) (Maynard and Curran 2008) at all sites except McPhee Creek. Total bulk density results from the sand replacement technique are found in Table 4. Soil samples from all sites were collected for bulk density, sieved, and oven-dried, and particle size (soil texture) was determined using the Bouyoucos Hydrometer method (Kalra and Maynard 1991) (Table 5). Surface carbonates were assessed on site using a 10% solution of HCl (hydrochloric acid). This was done for all plots at Mud Creek, Emily Creek, and Kootenay East. Summary data are presented in Table 6.

3.5 Soil and Seedling Nutrient Analysis

Soil samples were collected to determine soil nutrients. Six plots per treatment were randomly selected and 3 samples per tree species were collected for the 0–10 cm mineral layer. In addition, in the undisturbed treatments the surface organic horizon (LFH) was also collected. The samples were air-dried and passed through a 2 mm sieve. Chemical analysis included pH (Kalra and Maynard 1991), % carbon (C), % nitrogen (N) (LECO CNS analyzer), and exchangeable cations (inductively coupled plasma-optical emission spectrometer [ICP-OES]; Kalra and Maynard 1991).

An innovative technique was tried in addition to conventional soil sampling to estimate soil nutrient availability. Plant root simulator probes (PRS™ Probe [Western Ag Innovations Inc., Saskatoon, SK]) were installed and collected during the growing season (Appendix 8). Probe pairs (one cation, one anion) were installed within 15 cm of a seedling in a plot (Figure 8). The probes were eluted with 0.5 M HCl and analyzed for nitrate (NO_3^--N), ammonium (NH_4^+-N), calcium (Ca^{2+}), magnesium (Mg^{2+}), potassium (K^+), phosphorus (P in the form of $H_2PO_4^-$-P), iron (Fe^{3+}), manganese (Mn^{2+}), copper (Cu^{2+}), zinc (Zn^{2+}), boron (B in the form of $B(OH)_4^{3+}$-B), sulphur (S in the form of SO_4^--S), and (after 2002) aluminum (Al^{3+}) by Western Ag Innovations, Saskatoon, SK.

Figure 7. Measuring bulk density a) using a Troxler gauge on a deposit and b) using the sand replacement technique.

Table 4. Total soil bulk density (g/cm^3 ± standard deviation), followed by n (sample size).

Treatment (0–10cm)	Mud Creek	Emily Creek	Kootenay East	Rover Creek	McPhee Creek
Control	1.244 ±0.380 (4)	1.113 ±0.101 (4)	1.051 ±0.040 (4)	1.074 ±0.058 (4)	1.142 (1)
UNNC	1.125 ±0.200 (5)	1.075 ±0.146 (5)	1.008 ±0.089 (5)	1.129 ±0.141 (5)	n/a
UNLC	1.145 ±0.164 (5)	1.264 ±0.511 (5)	1.122 ±0.186 (5)	1.315 ±0.113 (5)	n/a
UNHC	1.173 ±0.143 (5)	1.211 ±0.317 (5)	1.071 ±0.145 (5)	1.434 ±0.124 (5)	n/a
SGNC	1.219 ±0.146 (5)	1.340 ±0.189 (5)	1.092 ±0.067 (5)	1.180 ±0.091 (5)	n/a
SGLC	1.298 ±0.110 (5)	1.330 ±0.260 (5)	1.237 ±0.147 (4)	1.462 ±0.065 (6)	n/a
DGNC	1.514 ±0.224 (5)	1.744 ±0.304 (5)	1.428 ±0.271 (5)	1.301 ±0.080 (5)	n/a
DGLC	1.436 ±0.060 (5)	1.686 ±0.103 (5)	1.431 ±0.204 (6)	1.577 ±0.235 (4)	n/a
DENC	1.003 ±0.194 (4)	0.848 ±0.214 (5)	1.102 ±0.240 (5)	0.897 ±0.362 (5)	n/a

n/a = not sampled.
UNNC=undisturbed, no compaction; UNLC=undisturbed, light compaction; UNHC=undisturbed, heavy compaction; SGNC=shallow gouge, no compaction; SGLC=shallow gouge, light compaction; DGNC=deep gouge, no compaction; DGLC=deep gouge, light compaction; DENC=deposit, no compaction.

Table 5. Soil texture at study sites.

Soil Depth (cm)	Mud Creek	Emily Creek	Kootenay East	Rover Creek	McPhee Creek
0–10	Loam	Loam	Silt loam	Loamy sand	Sandy loam
10–20	Clay loam	Loam	Clay loam	Sand	Silt loam
20–30	Clay loam	Sandy loam	Silt loam	Sand	Sandy loam
30–40	Clay loam	Sandy loam	Loam	Sand	Sandy loam

Table 6. Percentage of plots with carbonates.

	Mud Creek	Emily Creek	Kootenay East
UNNC	0	0	0
UNLC	0	0	0
UNHC	0	0	0
SGNC	14.3	0	9.5
SGLC	11.8	0	18.9
DGNC	68.1	0	90
DGLC	61.7	0	84.4
DENC	24.7	0	45.2

UNNC=undisturbed, no compaction; UNLC=undisturbed, light compaction; UNHC=undisturbed, heavy compaction; SGNC=shallow gouge, no compaction; SGLC=shallow gouge, light compaction; DGNC=deep gouge, no compaction; DGLC=deep gouge, light compaction; DENC=deposit, no compaction.

Figure 8. PRS^{TM} probe pair installed in soil.

Seedlings thinned at the end of year three will be separated into current foliage and all other foliage (non-current), current stem and rest of stem (non-current). Biomass will be determined for each part and then a subsample taken for nutrient analysis. The subsample will be oven-dried (forced air oven) at 70°C for 24 hours and ground using a coffee grinder. Total N, C, and S will be determined using the same method outlined above for the soil. Total Ca, Mg, K, P, Al, Fe, Mn, Cu, and Zn will be determined by ICP-OES following microwave digestion with concentrated nitric acid (70% HNO_3), concentrated hydrochloric acid (37% HCl), and hydrogen peroxide (30% H_2O_2) (Kalra and Maynard 1991).

3.6 Decomposition

Rate of decomposition is another measurement of potential nutrient availability. Wood decomposition is dependent on moisture, temperature, and biological activity. We used white birch tongue depressors (pre-dried at 50ºC [48 hrs] and weighed). Ten plots were randomly chosen for each of the eight treatments. In each of the 80 plots, a labelled string of three depressors was installed (one at 10 cm, one at 5 cm, and one just below surface of the litter/on the surface if there was no litter). A small hole was dug and a depressor inserted into a face of the hole at the appropriate depth to minimize soil disturbance (Figure 9). A landscape pin was used to keep the upper stick in place. These sticks were installed and collected as noted in Appendix 9. After collection, sticks were washed, dried at 50ºC (48 hrs), and re-weighed. Percent mass loss was then calculated.

3.7 Tree Growth

Growth measurements (tree heights and basal diameter) were carried out shortly after planting, but before seedlings had flushed. Tree measurements (height, basal diameter, and dbh [when trees reached 1.3 m height]) will be measured in the fall for the first 5 years and at years 8 and 10. Specific years for re-measurement are outlined in Appendix 10.

Figure 9. Installed set of three tongue depressors.

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Appendix 1. Mud Creek

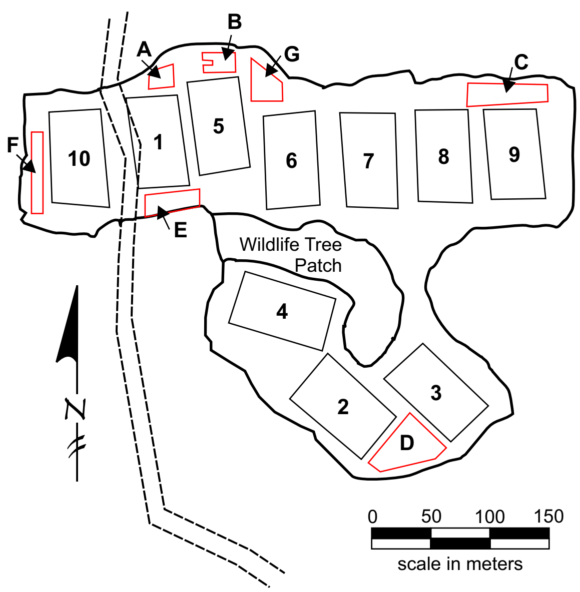
Kootenay/Boundary Region: Rocky Mountain District

Biogeoclimatic Zone: Interior Douglas-fir Kootenay dry mild variant (IDFdm2)

Dominant soil type: Orthic Eutric Brunisol (map 82J Kananaskis Lakes)

Area D	Soil Depth (cm)	Area A	Soil Depth (cm)
LFH	2–0	LFH	1–0
Ae	0–2	Ah(e)	0–3
Bm	2–18	Bm	3–22
BCk	18–28	BCk	22–36
Ck	28–60+	Ck	36+

Harvest: Done in winter 1998–1999 by Crestbrook Forest Industries Ltd. as per License FL A18978. To avoid excessive compaction in this area of sensitive soils, harvesting machine traffic was restricted to dry/frozen soils outside research areas and within plots there was hand falling and long-line skidding. Plots were established October 4–7, 1999 and planting occurred in May 2000.



Mud Creek Study Site
Plots 1–10: BC Ministry of Forests
Plots A–G: Canadian Forest Service

Appendix 2. Emily Creek

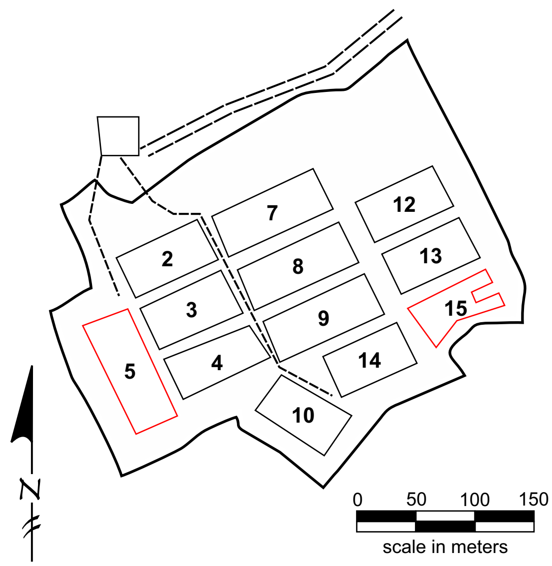
Kootenay/Boundary Region: Rocky Mountain District

Biogeoclimatic zone: Interior Douglas-fir Kootenay dry mild variant (IDFdm2)

Dominant soil type: Orthic Eutric Brunisol (map 82K Lardeau)

Soil Pit 1	Soil Depth (cm)	Soil Pit 2	Soil Depth (cm)
LFH	none	LFH	2–0 cm
Ah	none	Ah	0–2
Bm1	0–9cm	Bm1	2–16
Bm2	9–19	Bm2	16–28
Bm3	19–40	Bm3	28–48
		BCk	48–59
Ck	40–69+	Ck	59–69+

Harvest: Done in winter 1999–2000. To avoid excessive compaction in this area of sensitive soils, harvesting machine traffic was restricted to dry/frozen soils outside research areas and within plots there was hand falling and long-line skidding. Plots were established September 26–29, 2000 and planting occurred in May 2001 (lodgepole pine) and May 2002 (Douglas-fir).



Emily Creek Study Site
Plots 1–4 and 6–14: BC Ministry of Forests
Plots 5 and 15: Canadian Forest Service

Appendix 3. Kootenay East

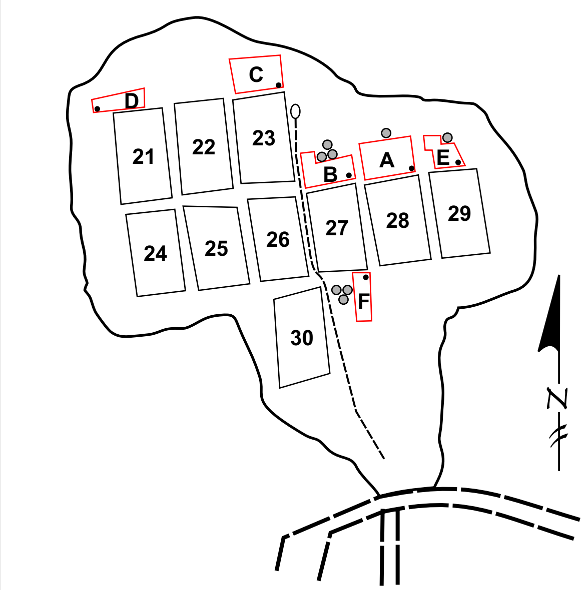
Kootenay/Boundary Region: Rocky Mountain District

Biogeoclimatic zone: Interior Douglas-fir Kootenay dry mild variant (IDFdm2)

Dominant soil type: Orthic Eutric Brunisol (map 82J Kananaskis Lakes)

Soil Pit 1	Soil Depth (cm)	Soil Pit 2	Soil Depth (cm)
LFH	4–0 cm	LFH	2–0 cm
Bm1	0–9	Bm1	0–8
Bm2	9–22	Bm2	8–24
BCk	22–27	BCk	24–35
Ck	27–50+	Ck	35+

Harvest: Done in winter 2000–2001 by Tembec Industries Inc. under License FLA 18978 (cutting permit 299 Block 360). Harvesting and yarding traffic was not allowed within research areas. Within plots, harvest occurred when ground was frozen and trees were felled toward plot edges and removed via longline skidding or hoe chucking. Treatments were applied October 24–26, 2001 and planting of Douglas-fir and lodgepole pine took place in May 2002.



Kootenay East Study Site
Plots 21–30: BC Ministry of Forests
Plots A–G: Canadian Forest Service
• Start of miniplot numbering
◦ Residual tree

Appendix 4. Rover Creek

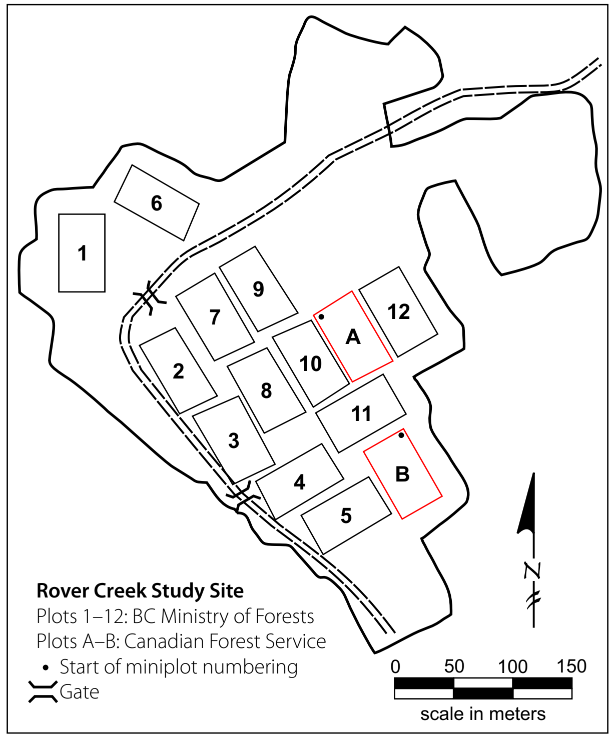
Kootenay/Boundary Region: Selkirk District

Biogeoclimatic zone: Interior Cedar–Hemlock Dry Warm Interior Cedar–Hemlock (ICHdw1)

Dominant soil type: Orthic Dystric Brunisol (map Trail 82F/SW)

Soil Pit	Soil Depth (cm)
LFH	5–0 cm
Ah	0–6
Bm	6–23
Bc	23–32
C	32–100+

Harvest: Done in 2001. Plots were established and treated in autumn 2002 with planting of Douglas-fir and western white pine in May 2003.



Appendix 5. McPhee Creek

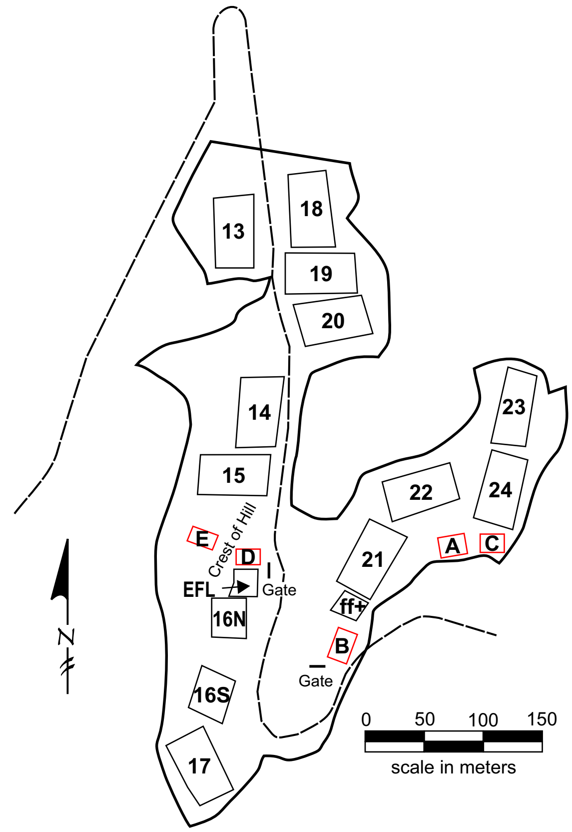
Kootenay/Boundary Region: Selkirk District

Biogeoclimatic zone: Interior Cedar–Hemlock Dry Warm Interior Cedar–Hemlock (ICHdw1)

Dominant soil type: Orthic Dystric Brunisol (map Trail 82F/SW)

Soil Pit	Soil Depth (cm)
LFH	4–0 cm
Ah	0–4
Bm	4–27
Bc	27–50
R	50+

Harvest: Done in 2002. Plots were established and treated in 2003 with planting of Douglas-fir and western white pine in May 2004.



McPhee Creek Study Site
Plots A–E: Canadian Forest Service
Remaining Plots: BC Ministry of Forests

Appendix 6. Mean Seedling Measurements Shortly After Planting

Mud Creek T=0 (May 9–11, 2000)	
Douglas-fir	Height=21.14 cm (4.04)[1] RCD[2]=3.94 mm (0.59)
Lodgepole pine	Height=18.36 cm (3.15) RCD=3.94 mm (0.51)
Emily Creek T=0	
Douglas-fir (May 13–14, 2002)	Height=16.64 cm (5.56) RCD=3.54 mm (0.63)
Lodgepole pine (May 8–9, 2001)	Height=13.02 cm (2.38) RCD=3.25 mm (0.35)
Kootenay East T=0 (May 15–16, 2002)	
Douglas-fir	Height=20.23 cm (5.00) RCD=3.54 mm (0.63)
Lodgepole pine	Height=11.95 cm (2.54) RCD=3.29 mm (0.40)
Rover Creek T=0 (May 13–14, 2003)	
Douglas-fir	Height=22.39 cm (4.22) RCD=3.46 mm (0.68)
Western white pine	Height=13.41 cm (2.71) RCD=3.39 mm (0.50)
McPhee Creek T=0	data not available[3]

1 Standard deviation in parentheses.
2 RCD=Root Collar Diameter.
3 T=0 seedling measurements were not done at McPhee Creek because of limited resources.

Appendix 7. Microclimate Station Information

Site	Measurements
Mud Creek (at 2 locations)	Air temperature @ 20 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 30 cm (UNNC) Soil water potential @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC)
Emily Creek (at 2 locations)	Air temperature @ 20 cm (UNNC[Blk15]), UNLC (Blk5), SGLC, DGNC, DGLC, DENC) Soil temperature @ 10 cm (UNNC[Blk15]), UNLC (Blk5), SGLC, DGNC, DGLC, DENC) Soil temperature @ 30 cm (UNNC[Blk15]), UNLC (Blk5) Soil moisture @ 10 cm (UNNC[Blk15]), UNLC (Blk5), SGLC, DGNC, DGLC, DENC) Rain gauge (2 locations)
Kootenay East (at 2 locations)	Air temperature @ 20 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 30 cm (UNNC) Soil moisture @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Rain gauge
Rover Creek	Air temperature and RH (relative humidity) @ 1.3 m Windspeed PAR flux density Solar radiation (solar flux density) Soil temperature @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 30 cm (UNNC) Soil moisture @ 10 cm (UNNC) Soil water potential @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Rain gauge
McPhee Creek	Air temperature and RH (relative humidity) @ 1.3 m Windspeed PAR flux density Solar radiation (solar flux density) Soil temperature @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Soil temperature @ 30 cm (UNNC) Soil moisture @ 10 cm (UNNC) Soil water potential @ 10 cm (UNNC, SGLC, DGNC, DGLC, DENC) Rain gauge

Appendix 8. Tongue Depressor Installation and Collection Schedule

	Years Since Planting				
Location	**1**	**2**	**3**	**4**	**5**
Mud Creek		Install set 1 (2001)	Collect set 1		
		Install set 2		Collect set 2	
			Install set 3	Collect set 3	
				Install set 4	Collect set 4
Emily Creek	Install set 1 (2001)	Collect set 1			n/a
	Install set 2		Collect set 2		
		Install set3	Collect set 3		
			Install set 4	Collect set 4	
Kootenay East	Install set 1 (2002)	Collect set 1			n/a
		Install set 2	Collect set 2		
			Install set 3	Collect set 3	
Rover Creek	Install set 1 (2003)	Collect set 1			n/a
		Install set 2	Collect set 2		
			Install set 3	Collect set 3	
McPhee Creek	n/a	n/a	n/a	n/a	n/a

Appendix 9. PRS™ Probe Installation and Collection Schedule

Site	Dates		Location	Total Number of Probes
	Inserted	Dug Up		
Mud Creek	June 12, 2000	July 11, 2000	Areas A, D and F	48
	May 10, 2001	June 7, 2001	Areas A, D and F	94
	June 7, 2001	July 5, 2001	Areas A, D and F	94
	July 5, 2001	August 1–2, 2001	Areas A, D and F	94
	May 16, 2002	June 13, 2002	Areas A, D and F	94
	June 13, 2002	July 10, 2002	Areas A, D and F	94
	July 10, 2002	August 7, 2002	Areas A, D and F	94
	May 15, 2003	June 11, 2003	Areas A, D and F	40
	June 11, 2003	July 8, 2003	Areas A, D and F	40
	July 8, 2003	August 7, 2003	Areas A, D and F	40
Emily Creek	May 10, 2001	June 7, 2001	Areas 5 and 15	32
	June 7, 2001	July 5, 2001	Areas 5 and 15	32
	July 5, 2001	August 2, 2001	Areas 5 and 15	32
	May 16, 2002	June 13, 2002	Areas 5 and 15	40
	June 13, 2002	July 9, 2002	Areas 5 and 15	40
	July 9, 2002	August 7, 2002	Areas 5 and 15	40
	May 16, 2003	June 13, 2003	Areas 5 and 15	40
	June 13, 2003	July 10, 2003	Areas 5 and 15	40
	July 10, 2003	August 8, 2003	Areas 5 and 15	40
Kootenay East	May 16, 2002	June 13, 2002	Areas A, B and C	40
	June 13, 2002	July 9, 2002	Areas A, B and C	40
	July 9, 2002	August 8, 2002	Areas A, B and C	40
	May 16, 2003	June 12, 2003	Areas A, B and C	40
	June 12, 2003	July 9, 2003	Areas A, B and C	40
	July 9, 2003	August 8, 2003	Areas A, B and C	40
	May 13, 2004	June 10, 2004	Areas A, B and C	40
	June 10, 2004	July 8, 2004	Areas A, B and C	40
Rover Creek	May 13, 2003	June 10, 2003	Areas A and B	40
	June 10, 2003	July 6, 2003	Areas A and B	40
	July 6, 2003	August 7, 2003	Areas A and B	40
	May 12, 2004	June 9, 2004	Areas A and B	40
	June 9, 2004	July 6, 2004	Areas A and B	40
	May 11, 2005	June 7, 2005	Areas A and B	40
	June 7, 2005	July 5, 2005	Areas A and B	40
McPhee Creek	May 26, 2008	June 22, 2008	Areas A–E	40
	June 22, 2008	July 20, 2008	Areas A–E	40

Appendix 10. Seedling Growth Measurement Schedule

Location	Tree Species	T=0 May	T=1 Sept.	T=2 Sept.	T=3 Sept.	T=4 Sept.	T=5 Sept.	T=8 Sept.	T=10 Sept.	Destructive Sample
Mud Creek	LP	2000	2000	2001	2002	2003	2004	2007	2009	Sept. 2002
	DF	2000	2000	2001	2002	2003	2004	2007	2009	n/a
Emily Creek	LP	2001	2001	2002	2003	2004	2005	2008	2010	Sept. 2003
	DF	2002	2002	2003	2004	2005	2006	2009	2011	n/a
Kootenay East	LP	2002	2002	2003	2004	2005	2006	2009	2011	Sept. 2004
	DF	2002	2002	2003	2004	2005	2006	2009	2011	n/a
Rover Creek	WWP	2003	2003	2004	2005	2006	2007	2010	2012	Sept. 2005
	DF	2003	2003	2004	2005	2006	2007	2010	2012	Sept. 2006
McPhee Creek	WWP	n/a	May	2005	2006	2007	2008	2011	2013	Sept. 2007
	DF	n/a	2005	2005	2006	2007	2008	2011	2013	

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