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Comparison of Post-Harvest Sample Designs To Assess Impact to Organic Forest Soils in Eastern Manitoba

By

Brian Brunsch ©

A Graduate Thesis submitted in partial

Fulfillment of the requirements for the degree of

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October 2001

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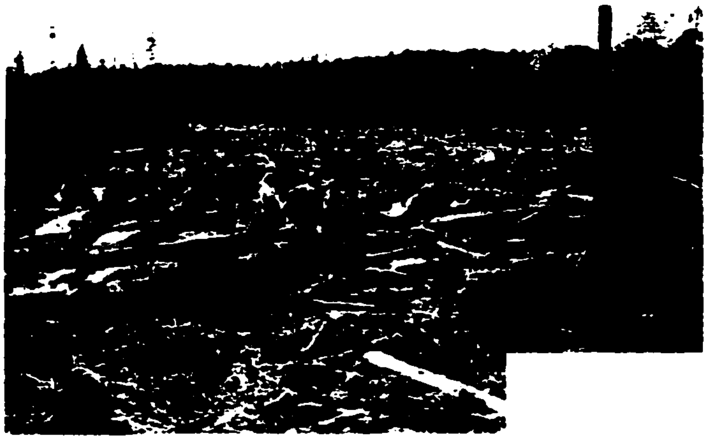

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October, 2001

ABSTRACT

Brunsch, B.P. October 2001. Comparison of Post-Harvest Sample Designs To Assess Impact to Organic Forest Soils in Eastern Manitoba. 86 pp. Advisor: Dr. H.G. Murchison.

Key Words: compaction, Manitoba, puddling, rutting, soils, soil sample design.

Five sampling methods were developed, tested, and compared to assess soil impact from harvesting equipment on organic sites in unfrozen condition. This study pointed to the gap in the literature for such a sample design. Suitability for utilization for the methods suggested was based on statistical and operational feasibility. The results from this study suggested situational assessment before choosing a sample design. The five designs within a harvested area included fixed area plots, randomly located transect intercepts, randomly located transect cluster intercepts, and two fixed start transect intercept designs. The fixed area plots recognized the most number of different disturbance types and also introduced the most variance. The random transect intercept method may prove useful and more accurate if implemented differently. The fixed start transect were not statistically justifiable and were investigated to fulfill an industrial mandate survey criteria. For the sites investigated, the plot design yielded the highest resolution of information. Although a complete economic analysis was not undertaken, the plot design may prove one of the most economical. Caution should be exercised when applying these designs to areas other than the study sites.

CONTENTS

TABLES

TABLES (cont'd...)

FIGURES

ACKNOWLEDGEMENTS

I would like to enthusiastically thank Pine Falls Paper Company and the Manitoba Model Forest for their financial and intuitive contributions. Thanks also to those who attended the field session at the inception of this study. Your comments set the underlying tones for this thesis. Much appreciation is extended to Dr. H.G. Murchison for his assistance and persistence. Many valued comments from Dr. W.L. Meyer and R. Clarke have been incorporated to further enhance this thesis. Thanks are also extended to Dr. Valerie LeMay, external reader from the University of British Columbia whose fresh ideas and extensive reviews have been included.

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October 2001

B. P. Brunsch

INTRODUCTION

Forest harvesting in an ecological and environmental context is often discussed in terms of impact on the local, regional and global landscapes. One area of key concern is the impact of wood procurement machinery on forest soils. Soils are one of the key ingredients to productive, sustainable forests. Disregard of their importance can lead to a loss of forest resources and a degradation of the landscape.

The boreal forest occupies about 77% of Canada's land area (Figure 1) and is key to the economic infrastructure for many communities in terms of both wood procurement and tourism.

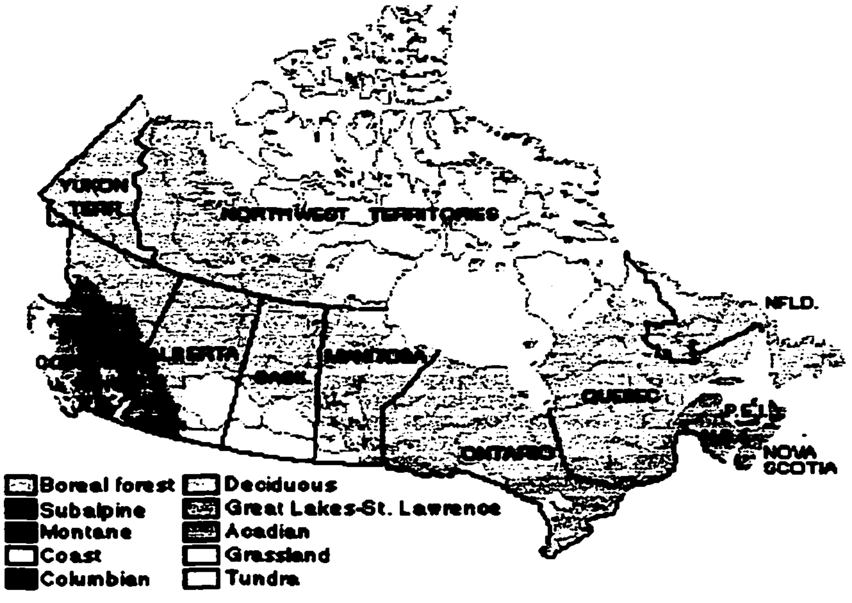

Figure 1. The forest regions of Canada (Hosie 1969).

Hosie (1969) described the tree species of the boreal forest as "white spruce (*Picea glauca* (Moench) Voss) and black spruce (*Picea mariana* (Mill.) B.S.P.) are characteristic species: other prominent conifers are tamarack (*Larix laricina* (Du Roi) K. Koch) which generally ranges throughout, balsam fir (*Abies balsamea* (L.) Mill.) and jack pine (*Pinus banksiana* Lamb.) in the eastern and central portions…". Hosie (1969) continued to describe the intermixed deciduous species in different areas especially where this forest zone joins other zones such as the Great Lakes – St. Lawrence forest zone.

This thesis focused on operable forest areas located in the boreal forest zone of Eastern Manitoba, more specifically the license limits of the Pine Falls Paper Company (PFPC) and the Manitoba Model Forest (MBMF). Although this thesis discussed past attempts to assess the impacts of harvesting on forest soils, the main objective was to evaluate existing sample designs, which adequately assess soil disturbance. Of particular interest was the disturbance of forest soils during wood procurement on organic soil sites in unfrozen conditions. Then, based on field information, literature, and thought, a field-based post-harvest assessment system was developed to meet statistical, operational, and economic parameters determined by the principal investigators and funding agencies.

LITERATURE REVIEW

One purpose of this thesis was to review and evaluate possible sampling techniques currently in the literature. Although little existed in reference to forest soil sampling on an operational basis, the related literature still proved useful. This review focused on aspects of soil impact of concern to forest managers and that is most applicable to the context of this thesis.

IMPACTS TO SOILS RELATED TO TREE ESTABLISHMENT AND GROWTH

Numerous studies have focused on soil impacts and some to plant growth. Herein are details of those most relevant to this thesis and related forest regeneration genera and site conditions found in the geographic location of this study. When discussing soil impact, terms that are often considered include soil compaction, rutting, and soil puddling. Soil compaction can be defined as a process that increases the density of a soil by packing thus causing a reduction in air volume but without a change in the volume of water (Craig 1997). A 'rut' is simply a concentrated area of compaction causing a noticeable depression. Lastly, puddling is a physical condition destroying the soil structure thereby causing the dispersing of soil particles that will eventually form a dense crust on the soil surface that will affect water penetration (Corns and Annas 1986) (Figure 2).

Figure 2. Soil impact on lowland site when harvesting completed in unfrozen conditions. Note the puddling in foreground.

In addition to the soil structure, the soil texture will affect growth and development of forest plant species. Soil texture is simply the amount of sand (S), silt (Si), and clay (CL) contained in the soil.

In an experiment by Foil and Ralston (1967), it was found that when loblolly pine (*Pinus taeda* L.) seedlings were grown on clay soils, they had lower mass than those seedlings grown on loams or sands. Also in this experiment, when the soils were loosened, growth was reduced on the light-textured soils, but significantly increased on clays. There did not seem to be differences whether the soil was lightly compacted or heavily compacted, seedling growth was reduced either way on all soils. There was little difference among any of the soil textures when compaction levels had exceeded the general threshold limits for seedling growth.

Hatchell *et al.* (1970) also examined growth response studies on disturbed soils. Of nine areas studied, two were chosen (randomness was not indicated) and response of naturally regenerating loblolly pine was surveyed and compared with adjacent undisturbed areas. The only site with significant differences for better stocking and height growth was found to be the primary skid trails on a site with fine sandy loam topsoil and clay loam subsoil.

Zisa *et al.* (1980) studied seedling establishment for urban reforestation and root penetration for three conifers at different bulk densities. The results of the experiment showed that a soil bulk density of 1.8 g/cm^3, the highest bulk density in the study, significantly reduced seedling establishment on silt loam soils. However, on a sandy loam plants became well established on the 1.8 g/cm^3 soils. When root penetration was examined, a noticeable reduction in root growth was discovered at a 1.4 g/cm^3 bulk density.

Burns and Honkala (1990) suggested that the maximum compaction for seedling establishment of north latitude species is about 1.4 to 1.5 g/cm^3. A soil that is below this bulk density may be visually impacted yet still be acceptable for regeneration.

In a study of ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.), Cochran and Brock (1985) found that early height growth of seedlings planted in clearcuts in central Oregon was negatively correlated with increasing soil bulk density. However, less than half of the total variation in height growth could be accounted for by the change in bulk density ($r^2 = 0.43$ to 0.47). Bulk density may have been a statistically significant contributor to the height growth difference, but other factors may have had an equal or greater influence.

Clayton *et al.* (1987) examined soil disturbance and tree growth relations in central Idaho clearcuts. In this study the effect of the penetration resistance was a negative correlation between radial growth, tree height, and tree diameter at breast height (d.b.h.) compared to an increase in bulk density on only one of the three study areas. This statement points out that seedling growth responses at two of the three sites are attributed to something other than soil bulk density. The authors gave two linear regression equations saying there is significance with the r-square value for diameter was 0.40, 0.32 for height, and 0.20 for radial growth.

Corns (1987) reviewed significant differences in aspects of lodgepole pine and white spruce seedling growth in relation to varying compaction rates of the study soils under greenhouse conditions. Intuitively, the results from this analysis make sense. The soil conditions with greater bulk densities had statistically significant impacts on seedling growth. However, before seedling germination, any soil clods found in the field soils were disturbed by crushing them to 2 cm in diameter or less. Since the soils were disturbed in this way, Corns (1987) cautions that it is likely that field compacted soils differ in structure and ability to support plant growth, when compared to those compacted in the laboratory.

PREDICTING AND MONITORING SOIL DEGRADATION

Scientific Prediction Models

Soil researchers and environmental scientists have pondered the effect forest operations have on soil productivity. By completing studies on the effects soil disturbance has on tree growth, there is hope that an ability to quantify the impacts of forest harvesting will result. However, the complexity of what actually happens to soil properties under normal harvest and silvicultural activities is difficult to visualize. McNabb and Campbell (1985) attempt to show this complexity with a flowchart-type diagram as seen in Figure 3. Based on this high level of complication and interaction, McNabb and Campbell (1985) suggested that a model that predicts the impact of forestry activities on soil productivity is unrealistic and impractical except on an extremely local (possibly site to site) basis.

Arnup and McBride (1997) completed a predictive model study in the Clay Belt Region of Northeastern Ontario, Canada on fine loamy to clayey soils. Table 1 presents a summary of the physical soil characteristics of the two study sites from Arnup and McBride (1997). Site S13 consisted of Silty Loam (SiL) to Silty Clay Loam (SiCL) soils and Site S15 had Silty Clay Loam to Clay (C) soils. This table presents some notable information including the variation of bulk densities between sites within the same geographical area and gives some indication of tolerable bulk densities for rooting in clay soils (only upper most one or two horizons have evidence of rooting).

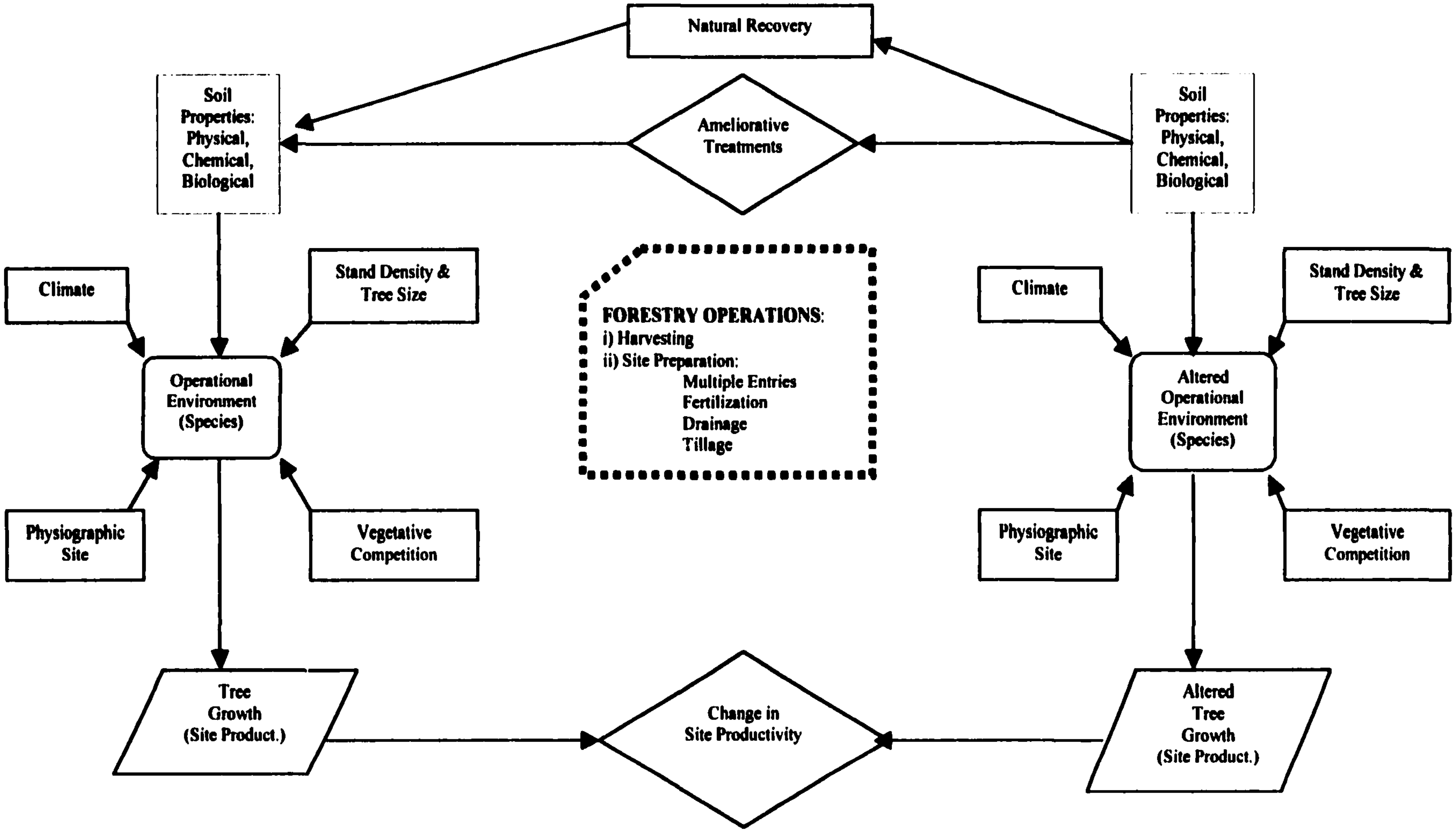

Figure 3. Forestry operations interaction with soil (McNabb and Campbell 1985).

Table 1. Physical soil characteristics of the Arnup and McBride (1997) study sites.

Study Site	Soil Horizon	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	Texture Class	Dry Bulk Density (g cm-3)	Organic Carbon (% kg kg-1)
S13	Ah/Bm	0-5	28	54	18	SiL	0.983	2.09
	Bm	5-25	16	54	30	SiCL	1.169	0.61
	Bt	25-45	16	54	30	SiCL	1.436	0.61
	Ck	45+	11	56	33	SiCL	1.588	0.74
S15	Ah	0-5	21	47	32	SiCL	1.01	5.74
	Bm/Bt	5-30	12	41	47	C	1.52	0.65
	Bt	30-60	12	41	47	C	1.49	0.65
	Ckg	60+	15	48	37	SiCL	1.63	0.06

Using a soil water balance model, SWATRE, developed in 1978 by Feddes *et al*, Arnup and McBride (1997) entered certain data to come up with an estimate of the soil's trafficability at different times of the year. Elements in this study included:

- past meteorological data;
- soil bulk density;
- Atterberg limits;
- potential evaporation;
- net radiation;
- soil water retention;
- residual water content;
- daily groundwater depths;
- leaf area index and;
- rooting depth.

Simple regression analysis techniques were used to determine predicted liquid limits (% kg kg-1) and water retention relationships (kg kg-1). In the analysis output presented for the Arnup and McBride (1997) article, all points were located below the function line (a graphic representation of a mathematical equation), thus indicating there is a continuous over-prediction of the potential gravimetric water content. In their discussion, Arnup and McBride (1997) attributed this over-prediction possibly to laboratory error, but later mentioned that the equation was used anyway.

Although the study was in an agricultural context, Hakansson and Voorhees (1997) were able to establish upper limits of optimal dry bulk density for plow layers (Figure 4).

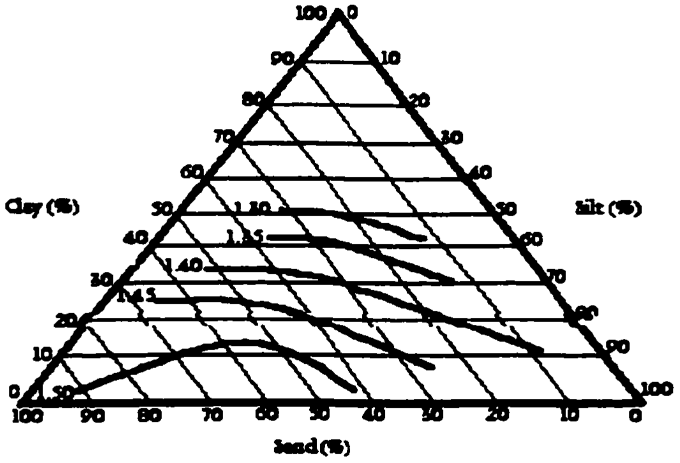

Figure 4. Approximations of the upper limit of the optimal dry bulk density range (Mg/m^3) in the plow layer as a function of the soil texture (Hakansson and Voorhees 1997).

This bulk density estimation system developed by Hakansson and Voorhees (1997) was based primarily on the soil texture. To accurately determine soil texture, laboratory analyses are required making this type of system less than optimum for field implementation and immediate results.

Forestry Terramechanical Approaches

Hatchell *et al.* (1970) completed field trials to study the effects of logging on soil qualities and initial loblolly pine growth in the lower coastal plains of South Carolina and

Virginia in the United States. A treatment distinction was made by classifying each of the logged areas as log decks, primary skid trails, secondary skid trails, and undisturbed areas. Soil density and moisture data were collected using a nuclear densiometer. As well, a repetitive pass vehicle study was completed using a crawler tractor and a two-wheeled trailer at 47 locations within an experimental forest in South Carolina. Soil density and other measurements were taken exclusively in the trailer tracks (Table 2).

Table 2. Soil properties classified by type of disturbance (Hatchell *et al.* 1970).

Type of Disturbance	Bulk Density (g/cm^3)	Soil Strength (kg/cm^2)	Infiltration Rate (in./hr)	Air Space (% by vol.)
Log deck	1.14	3.4	2.6	26.2
Primary skid trail	1.08	2.8	2.7	23.1
Secondary skid trail	0.92	2.1	5.5	27.5
Undisturbed soil	0.75	1.1	25.2	38.5

Hatchell *et al.* (1970) also presented some discussion of vehicular compaction results, soil recovery rates, and growth response on disturbed soils. Hatchell *et al.* (1970) commented that a very sharp increase in bulk density of the sandy loam surface soils occurred after one or two trips and a more gradual increase in density as the number of trips increased. Some difficulties encountered during these trials included some disturbances were completed on one soil type, while the remaining impacts on another type and it is possible that there was variation between the soils at each site.

PREVENTING SOIL DEGRADATION

In addition to pre-harvest assessment, certain forest management decisions can be made to restrict soil degradation including procurement machinery specification (such as tire selection for skidders), and comprehensive pre-harvest planning decisions (such as optimum skid trail layout prior to harvest).

Selecting Machinery for Wood Procurement

Although the study focused on productivity and fuel consumption estimates, Mellgren and Heidersdorf (1984) also examined ground disturbance of high flotation tires. Table 3 outlines the tire used in the repetitive test passes and Table 4 gives the results.

Table 3. Test tire description (extracted from Mellgren and Heidersdorf 1984).

Tires	Conventional	Firestone	Rolligon	United "Swamper"
Overall Diameter (cm)	180.34	167.64	137.16	172.72
Width (cm)	62.23	109.22	172.72	127.00
Footprint (cm^2)	11 223	18 310	23 690	21 935
Footprint pressure (kPa) with 2400 kg load per tire.	42	26	20	21
Approximate weight of tire & rim (kg)	375	500	400	800

Table 4. Repetitive pass test results (extracted from Mellgren and Heidersdorf 1984).

Pass	United	Firestone	Rolligon
	% of Track with Exposed Organic Soil (Muck)		
10	58	2	2
12	stuck	--	--
14		--	--
16		--	--
18		26	4
20		50	--
22		stuck	16
24			--
26			33

From these results, it can be concluded that in clay soils such as those used in the Mellgren and Heidersdorf trials (1984), the footprint area and tire ground pressure are considerable factors affecting the amount of organic matter disturbed over a soil and possibly soil compaction as well.

Novak (1988) completed a study similar to Mellgren and Heidersdorf (1984). The site for this project was north of Amos, Quebec, Canada, and trials were completed in August and September 1985. In this investigation, a comparison was made between a large skidder (John Deere 640B) with conventional tires and a smaller John Deere 540B with wide flotation tires. The main objective of the study was to compare productivity of the machines, but ground disturbance data were also collected. A summary of the results of site disturbance is presented in Table 5. The methodology regarding the collection of this data was vague, but the author did state that it is "a systematic point-sampling method developed by the MER (Ministère de l'Energie et des Ressources du Québec) that was employed. The first 20 m from the roadside were excluded from the sample since the road drainage and heavy skidder traffic made this area unrepresentative" (Novak 1988).

Table 5. Ground disturbance comparison from the Novak (1988) trials.

Machine Configuration	JD 640B Conv. Tires and Chains	JD 540B Wide Tires
Undisturbed (%)		
Outside tire tracks	34	32
Between tire tracks	9	12
Disturbed (%)	57	56
Breakdown of Disturbed Ground (%)		
Depth (cm)		
0 – 15	7	83
16-30	18	11
31-60	36	4
61-100	38	2
100 +	1	0

Although the study by Gingras *et al.* (1991) focused on the protection of advanced regeneration using different skidding machinery, the authors also offered valuable site disturbance information. The study was performed north of Mistassini, Quebec, Canada and three skidding machines were compared including:

- a Treefarmer model C7D cable skidder with 81 cm wide chained tires;
- a Treefarmer model C7E grapple skidder with 81 cm wide chained tires; and
- a FMG Lokomo 933 clambunk skidder with 65 cm wide tracks.

Survey methodology used to collect the area of disturbance data was not defined, but it does appear that a classification was made as to the level of disturbance. Three categories presented by Gingras *et al.* (1991) included none, light, and severe. Light disturbance can be interpreted as crushed vegetation or litter, severe disturbance at exposed humus or mineral soil. The results from this survey are presented in Table 6.

Table 6. Level of site disturbance (Area %) after harvesting (Gingras *et al.* 1991).

Skidder	Block	Level of Disturbance (%) None	Light	Severe
Cable	C1	66.5	17.0	16.5
	C2	60.5	16.5	23.0
Grapple	G1	68.0	23.0	9.0
	G2	54.0	12.5	33.5
Clambunk	B1	77.0	6.5	16.5
	B2	69.0	16.5	14.5

The authors concluded that it was the pre-harvest planning that determines the level and area of disturbance after harvesting and not necessarily, the type of equipment used.

Krag *et al.* (1993) completed a terramechanical study in the East Kootenays of British Columbia, Canada. This particular study consisted of measuring the soil bulk densities after being disturbed by five different skidding machines with associated trail building techniques. Bulk densities were taken using a nuclear densiometer and measurements were made at five different microsites on the skid trail. Krag *et al.* (1993) found that the soil bulk density increases with the tracked vehicles were described as 'significant' (15% to 18% increase) with fewer than five passes. The rubber-tired skidders had a 'modest' affect (10% to 12% increase in soil bulk density) after 15 passes (Krag *et al.* 1993). It should be noted that there are considerable differences between skid road planning and implementation between the Kootenay Region of British

Columbia and organic sites in Eastern Manitoba. This area of British Columbia will have outwash origin mineral soils on moderate to steep topography. The soils for the study areas for this thesis were flat to slightly rolling topography with deep, wet, organic soils.

Forest Management Planning

One planning option might be the prescription of various interventions following harvest before the establishment of the regeneration crop. The use of silvicultural equipment seems to have varied effects on relieving a soil from compaction; thus, a more consistent form of alleviation should be pursued. While reviewing the effectiveness of certain silvicultural machines to reduce soil compaction, Froehlich and McNabb (1983) suggested:

> Restricting machine operation to a limited number of preplanned, designated skid trails is currently the most efficient method [of reducing compaction]. Tillage techniques that more effectively loosen compacted forest soil are becoming available; however, tillage may be less effective than planning future harvesting operations to minimize compaction.

Planning of primary wood transport (skidding operations), the management forester would arguably reduce the area impacted by equipment. The extent of this effectiveness, however, has not been clearly defined in formal literature.

FORESTRY PRE-HARVEST HAZARD RATING SYSTEMS

Under the Canada – Alberta Forest Resource Development Agreement, Corns and Annas (1986) were able to develop pre-harvest compaction risk assessment keys for West – Central Alberta (Table 7).

Table 7. Soil compaction hazard table for West – Central Alberta (extracted from Corns and Annas 1986).

Texture[2]	Coarse Fragments	Humic Layer Thickness	Structure	Character of Coarse Fragments	Rating[3]
L, SiL, SiCL, CL	< 35%	< 5 cm	Strong	All	M
			Mod. & weak	All	H
Si, hSL, vfSL		> 5 cm	Mod. & weak	All	H
			Strong	All	M
	35-60%	< 5 cm	Mod. & Weak	Rounded	M
				Angular	M
			Strong	All	L
		> 5 cm	Mod. & Weak	Rounded	L
				Angular	M
			Strong	All	L
	> 60%	Any	All	All	L
LS, S	Any	Any	All	All	L
	> 35%	Any	All	All	L
SiC, C, SC, SCL	< 35%	< 5 cm	Strong	All	L
			Mod. & Weak	All	M
		> 5 cm	Strong	All	M
			Mod. & Weak	All	L

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[2] Texture symbols are as follows: L = loam(y), Si = silt(y), C = clay, S = sand(y), h = heavy, and vf = very fine.

[3] L = low, M = moderate, and H = high. In making a rating consider the characteristics of the litter and upper 30 cm of mineral horizons. A wet or moist condition is assumed. The horizon that gives the poorest rating is used.

McNabb (1998) commented that Table 7 is largely based on research completed in the United States and have been applied with little ground testing. Although Corns and Annas (1986) mention "most soils of the study area....", there is no evidence to indicate a thorough study was completed. Instead, the authors may be referring to the 'area of inference' rather than a 'study area'.

The British Columbia Ministry of Forests (BCMoF) (1995), with the development of the Forest Practices Code of British Columbia, developed a hazard assessment key for soil sensitivity to impact. With particular respect to soil compaction and puddling, a definition of soil compaction was introduced as "the increase in soil density that results from the rearrangement of soil particles in response to applied external forces" (BCMoF 1995). Whereas, soil puddling is "the destruction of soil structure and the associated loss of macroporosity that results from working the soil when wet" (BCMoF 1995). Site factors determining hazards as defined by the BCMoF (1995) include:

- the soil texture;
- coarse fragment content of the soil;
- moisture regime of the soil;
- if the forest floor humic horizon is greater than or equal to 20 cm; and
- if the soil is an organic soil.

Throughout the publication, the BCMoF (1995) defines a coarse fragment as a mineral soil particle greater than 2 mm in diameter. For a soil to be considered an organic soil in this context, it is composed of more than 40 cm of wet organic material, or forest floors greater than 40 cm, including Folisols less than 40 cm (BCMoF 1995).

The BCMoF (1995) further outlined management considerations when looking at soil compaction and puddling hazards as:

- applied forces including equipment ground pressure and number of passes;
- scheduling of operations;
- scalping;
- slope;
- frozen soil > 15 cm deep;
- compressible snow > 1 m; and
- seasonal soil moisture content.

The BCMoF developed a soil compaction and puddling hazard key (Figure 5).

Soil Texture [a] **(0 – 30 cm)**		**Hazard rating** [b] moisture regime	
		Xeric – Subhygric [c] (H horizons < 20 cm)	Subhygric [d] – subhydric [d](H horizons ≥ 20 cm)
Fragmental (coarse fragments > 70 %)		L	M
Coarse Fragments **(<70%)**	Sandy[e] S, LS	L	VH [i]
	Sandy loam[f] SL, fSL	M	
	Silty/loamy[g] SiL, Si, L	H	
	Clayey[h] SCL, CL, SiCL, SC, SiC, C	VH	

[a] Use dominant soil texture and coarse fragment content of the upper 30 cm of mineral soil to assess compaction hazard. If a pronounced textural change occurs within the upper 30 cm (e.g. silty over sandy soil), then use the more limiting soil texture, providing it amounts to 5 cm of the top 30 cm.

[b] L – Low; M = Medium; H = High; VH = Very High.

[c] Use this column for subhygric sites with forest floor H horizons < 20 cm thick.

[d] Use this column for subhygric sites with forest floor H horizons ≥ 20 cm thick.

[e] S = sand, LS = loamy sand.

[f] SL = sandy loam, fSL = fine sandy loam (for the purposes of this key fSL, "fine sandy loam" means the soil contains 30 per cent or more fine or very fine sand, or more than 40 per cent fine and very fine sand combined. Fine sand is 0.25 to 0.10 mm in diameter, very fine sand is 0.10 to 0.05 mm in diameter. These generally represent the limits of visible particles.

[g] SiL = silt loam, Si = silt, L = loam.

[h] SCL = sandy clay loam, CL = clay loam, SiCL = silty clay loam, SC = sandy clay, SiC = silty clay, C = clay.

[i] Organic soils composed of more than 40 cm of wet organic material, or forest floors >40 cm(including Folisols < 40 cm), are susceptible to rutting by displacement of their very low load-bearing strength materials. Consequently, these organic materials have a high soil displacement hazard and a very high puddling hazard.

Figure 5. BCMoF soil compaction hazard key (BCMoF 1995).

More recently, the Ontario Ministry of Natural Resources (OMNR) published pre-harvest hazard rating systems (Archibald *et al.* 1997). With heavy reliance on the Forest Ecosystem Classification (FEC) system for the three Ontario areas, this rating seems to refer to Best Management Practices (Table 9). This partial reproduction from Archibald *et al.* (1997) is for Northwestern Ontario soil types. Ratings for Northeastern and Central Ontario are included in the original manuscript. Along with the advisories for the site-damage hazard ratings, Archibald *et al.* (1997) also offered elaboration for each soil moisture condition in the text. It should be noted that this hazard system is based on literature review and 'expert opinion' (Archibald 1997b).

Table 8. Compaction and rutting hazard for Northwestern Ontario soils (Archibald *et al.* 1997).

Soil Description			FEC Soil Type	Soil Damage Hazard Rating by Soil Moisture Condition			
Texture	Mineral Soil Depth (cm)	Organic Soil Depth (cm)	Northwestern Ontario	Frozen	Dry	Moist	Wet
mineral – all	0-5	0-20	SS1, SS2, SS4	Low	low	mod.	high
mineral-all	6-30	0-20	SS3, SS4, (SS5-SS8)	Low	low	mod.	high
sandy	31-60	0-20	SS5, (SS8)	Low	low	low	mod.
sandy	61+	0-20	S1, S2, S7, (SS5, SS8)	Low	low	low	mod.
coarse loamy	31-60	0-20	SS6, (SS8)	Low	low	mod.	high
coarse loamy	61+	0-20	S3, S8, (SS6, SS8)	Low	low	mod.	high
silty	31-60	0-20	SS7, (SS8)	Low	low	mod.	high
silty	61+	0-20	S4, S9, (SS7, SS8)	Low	low	mod.	high
f. loamy-clayey	31-60	0-20	SS7, (SS8)	Low	low	mod.	high
f. loamy-clayey	61+	0-20	S5, S6, S10, (SS7, SS8)	Low	low	mod.	high
organic-fibric	All	21-40	SS9, S11	Low	mod.	high	high
org.-mesic/humic	All	21-40	SS9, S11	Low	mod.	high	high
organic – fibric	All	41+	SS9, S12F, S12S	Low	mod.	high	high
org.-mesic/humic	All	41+	SS9, S12F, S12S	Low	high	high	high

Note: Brackets () indicate that these soil types are not closely related to the soil description i.e. they are defined by other soil parameters and may be found on several lines in the table.

Site Damage Hazard Rating

Low: *Minimal Risk of compaction and rutting, provided normal care is exercised during forest operations.*

Moderate: *Normal operating procedures may cause compaction and rutting. The use of Best Management Practices will normally avoid or minimize site damage.*

High: *Normal operating procedures will cause site damage. Best Management Practices may be able to minimize damage, however, in many cases operations should not be conducted until conditions change.*

Forestry Post-Harvest Assessments

It may not have been the initial study dealing with the matter of harvesting and soil compaction, but Dyrness (1965) provides a turning point in the sample design for future studies. This design was intended to determine the extent of soil surface disturbance after yarding near Blue River, Oregon, U.S.A.. The classification system for disturbance by Dyrness (1965) was:

- Undisturbed - litter still in place and no evidence of compaction;
- Slightly disturbed – three conditions fit this class including:
    1) litter removed and undisturbed mineral soil exposed;
    2) mineral soil and litter intimately mixed with about 50 percent of each; and
    3) pure mineral soil deposited on top of litter and slash to a depth of 5 cm;
- Deeply disturbed – surface soil removed and the subsoil exposed. The soil surface is very seldom covered by litter or slash; and
- Compacted – obvious compaction due to passage of a log or mobile equipment. The soil surface under large cull logs is assumed to be in this condition.

Some difficulties were encountered when interpreting this system. In the article, there is no mention of sample unit size or sample intensity. The system by Dyrness (1965) did not consider compaction of the soil that is not detrimental.

In a study in Southwestern British Columbia, Canada, Bockheim *et al.* (1975) described immediate soil disturbance after harvesting using different logging methods. As with many indices of soil disturbance, the main categories were based on the level or intensity of disturbance including undisturbed, forest floor disturbed (without mineral soil exposure), shallow soil disturbance (up to 5 cm in depth), and deep soil disturbance. In reviewing the methodology of the study, Bockheim *et al.* (1975) stated:

> In each clearcut [of the sixteen studied], a transect line was extended by taking along a compass bearing, across the slope at a position approximately midway between the main haul road and the upper boundary of the clearcut, thereby avoiding sidecast soil material from haulroad construction. However,

> in tractor-logged areas, transects included skid trails and sidecast material not associated with main haul roads. Transects ranged from 160 to 550 m in length, averaging 325 m. Sample points were located every 1 to 3 m depending on the transect length to provide a minimum of 100 points in each clearcut.

This is very similar to the design introduced by Dyrness (1965). A primary difficulty raised with this design includes the fixed start and fixed location of the transect line. Systematic sampling such as this is not incorrect, in fact, many systematic sampling designs have been successfully implemented in a variety of situations. A systematic design does not allow the use of analytic techniques developed for random sampling. There can be bias of an unknown quantity in the estimate of the mean and the standard error since the chance of selecting one sample unit versus another may not be equal (Cochran 1977).

In addition to providing sample criteria similar to those already mentioned, Smith and Wass (1976) introduced confounding factors to measuring soil disturbance. Such factors could include (but are not limited to) the yarding method, snow conditions at time of logging, the post-harvest treatment (Smith and Wass 1976), as well as soil moisture, soil texture, coarse fragment content, and soil pore space.

A similar level of disturbance tally is seen in Schwab and Watt (1981). This study, which took place east of Williams Lake, British Columbia, Canada, involved running transects across contours from the lower to upper boundaries of the harvest area. Two yarding methods were sampled; a crawler tractor system and a running skyline system. Point observations were made and recorded at three metre intervals along the transects. At each point, disturbance was classified as (Schwab and Watt 1981):

- Not disturbed – no visible alteration of the forest floor;
- Forest floor disturbed – visible disruption of the forest floor but no mineral soil exposure;
- Shallow disturbance – mineral soil exposed and the removal and/or deposition of soil, less than 25 cm in depth;
- Deep disturbance – the removal and/or deposition of soil to a depth greater than 25 cm;
- Mineral soil exposed – removal of the forest floor exposing mineral soil, shallow and deep disturbance.

To determine the amount of disturbance, the categories were expressed as a percentage of the total number of samples (Schwab and Watt 1981). Thus, it is assumed that the tally at each of the points was simply a presence or absence and then the percentage of presence over the number of point samples was calculated. However, to simply tally the presence of impact does not indicate to the forest manager if the area is beyond suitability for forest regeneration.

Sidle and Drlica (1981) studied soil compaction from logging with a low-ground pressure skidder in Oregon. The area was a partial cut (removing one third of the total volume) of Douglas Fir (*Pseudotsuga menziesii* (Mirb.) Franco) on clay loam soils. Soil bulk density samples were taken at depth measures of 7.5cm, 15cm, 22.5cm, and 30 cm.

It is apparent from the results of Sidle and Drlica (1981) that the soils were extremely variable. Soil bulk density increases at the 7.5 cm depth ranged from -27.6% to 109.2%, -7.2% to 82.4% at the 15 cm depth, -13.3% to 68.7% at the 22.5 cm level, and -26.6% to 53% at the 30 cm depth measurement compared to original pre-disturbance readings. The only general trend that can be noticed from the data is, traffic has higher compaction effects on upper soil horizons than on deeper soil horizons. The negative responses (-) seem to indicate there may be other factors causing a natural amelioration from the machines or that there is a significant variation between pre and post disturbance sampling units.

REPAIRING THE DAMAGE - NATURAL AMELIORATION FROM COMPACTION

When discussing soil rates of recovery, Hatchell *et al.* (1970) stated that there were no noticeable trends towards partial recovery of compacted soils during a one-year period. So, in sandy loam soils, it does not appear that amelioration from soil compaction is immediate.

Set in an agricultural context, Blake *et al.* (1976) used hydraulic conductivity as a measure of compaction. In 1960, the Mollisol site (a clay loam) was subjected to compacting efforts. Hydraulic readings 10 years later showed marked differences between treated and untreated areas: there were compaction reductions of 41 to 77% in the 21 to 48 cm depth class of parent material.

In northern settings, such as the boreal forest zone, it is often thought that frost penetration and heaving will loosen the compaction of forest soils. Froehlich and McNabb (1983) refute this belief stating that resolution of bulk density in cold climates by frost penetration may not be as great as previously believed. They caution that until further specific studies are completed, it should be assumed that compaction persists for several years following disturbance.

Each of the four sites of study in Corns (1987) was of varying soil textures and drainage classes as depicted in Table 9. Table 10 presents the estimated recovery times by site and depth class in years.

Table 9. Summary of site properties of sample areas (Corns 1987).

Soil Association	Parent Material	Texture	Drainage	Soil Subgroup	Forest Conditions Sampled
Lendrum	Glacio lacustrine	Silty Clay	Moderately well to imperfect drainage	Orthic Gray Luvisol	Lodgepole pine, mature, uncut; clearcut 4, 11, and 19 years
Marlboro	Cobbly glacial till	Clay Loam	Moderately well to well drained	Brunisolic Gray Luvisol	Lodgepole pine, mature, uncut; clearcut current, 4, 17, and 24 years
Summit	Cobbly Tertiary fluvial	Sandy loam – clay loam	Well to rapidly drained	Brunisolic Gray Luvisol	Lodgepole pine, mature, uncut; clearcut current, 12, and 20 years
Hinton	Eolian	Silt loam – loam	Well to imperfectly drained	Cumulic Regosol	White spruce, mature, uncut; clearcut current, 6, 13, and 23 years

Table 10. Estimated soil bulk density recovery times (Corns 1987).

Soil Association and Depth (cm)	Estimated Recovery Time (years)
Lendrum	
0	17
10	14
20	14
30	13
Marlboro	
0	21
10	20
20	18
30	17
Summit	
0	Recovered
10	Recovered
20	Recovered
30	Recovered
Hinton	
0	13
10	12
20	10
30	15

In the footnote of Table 10 in the original manuscript, the author stated that recovery times were assumed to follow a linear trend. This paper is one of very few studies on natural amelioration from soil compaction. Little is known about recovery times and the utilization of a linear trend as a general rule should be examined further before full operational implementation.

Although not specifically studying the freezing action on soils, McNabb (1994) suggests that drier soil is expected to be only slightly more susceptible to fracturing into smaller clods. The freezing of remolded soil, while apparently not decreasing bulk density, may reintroduce fracture planes in as little as one or two years leading to enhanced soil fracturing during disturbance. (McNabb 1994).

Based on this literature review, minimal literature in refereed journals was found about the soil impact effects, sampling of impact on, and amelioration of organic soils subjected to wood procurement in unfrozen conditions. Instead, most studies have focused on mineral and/or parent material soil horizons. This may be due in part to the lack of wood procurement operations on organic soils in other geographic locations of the scientific community and the limited accessibility to many organic sites. There may be as well an untapped source of knowledge outside refereed journals in the experience of woodlands operations managers.

OBJECTIVES

This thesis is intended to develop a post-harvest assessment system to assess soil impact from wood procurement operations. More specifically, this thesis focuses on wet organic soils harvested in unfrozen conditions.

The Canadian Council of Forest Ministers criteria (CCFM (1997a)) indicates the assessment of the area of impact and the greatest impacts from forest harvesting on these organic sites would include slash accumulation, harvest rutting, and apparently undisturbed areas as a measure of soil impact. This thesis develops an assessment system to quantify these parameters keeping in mind operational and economic limits faced by forest managers.

PROJECT METHODOLOGY

To begin the field season in 1998, a workshop was held in Pine Falls, Manitoba, Canada. Representatives were invited from various forest companies in the province, Manitoba Model Forest Staff, FERIC (Forest Engineering Research Institute of Canada), private forestry consultants, and the project team. The primary objective of the workshop was to collectively gain a better understanding of soil impacts from harvesting, the duration of the impact, and to solicit ideas on how to sample this situation.

Following the workshop, it became apparent that there was high variation of soil conditions and soil-site conditions following harvesting. To help define this diversity, a matrix of soils and site characteristics was developed. A purposive, non-random survey was carried out in the field using a 1m by 1m collapsible square. Going into recent cutovers of various soil types and placing the quadrat at various sites gave a perspective of the range of 'microsites' (sites which would support timber regeneration) to be found.

Examination of the final product of this matrix warranted constraint of the site types to be assessed. At this stage, it was decided between the project team and the funding partners that focus would be shifted towards lowland areas harvested under unfrozen conditions. Recent (one to two year old) candidate blocks with appropriate soil conditions and accessibility were selected.

The next phase of the project field surveys had two parts. First, recently harvested candidate lowland blocks were divided into a grid pattern of 20 m by 20 m with a randomly located starting location. Twenty metre intervals were used since this distance corresponds to the PFPC pre-harvest plot interval. Using this distance may aid in developing corresponding matrices between pre and post harvest ground conditions. At each intersection of the grid, a 1m by 1m quadrat was placed squarely on the ground (see Figure 6) to yield a 0.25% sampling intensity (1m^2 sampled per 400 m^2 of harvested area). Use of the 1 m^2 quadrats was again related to the pre-harvest surveys in an attempt to harmonize the two sampling methods. Assessment was made of each disturbance type occurring in the quadrat with a corresponding estimate of percentage to the nearest deca-percentile. Notes and corresponding coverage of occupying vegetation and the presence and number of regenerates were also taken. It is important to note that this is a visual assessment methodology. Development of more intensive methods may be more accurate but the importance of future implementation had to be enforced.

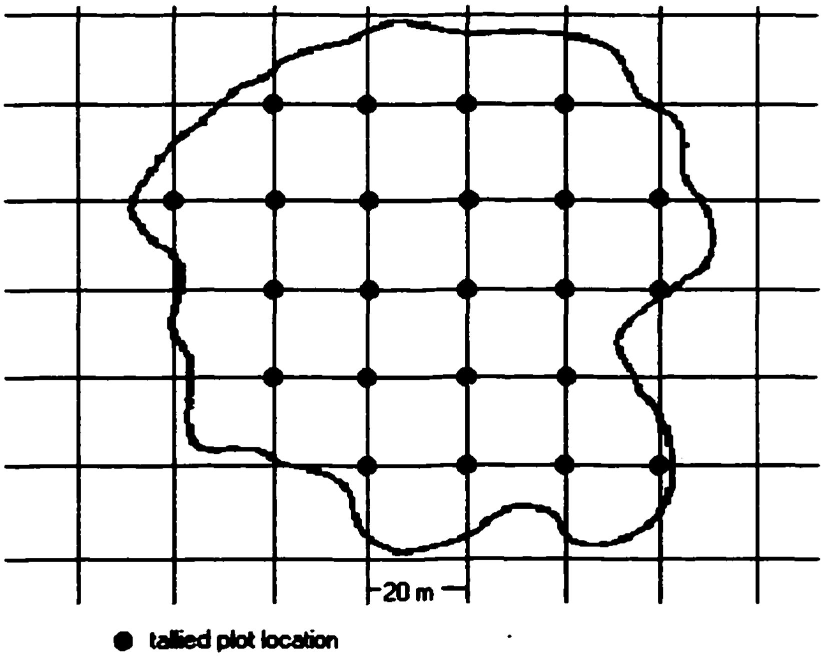

Figure 6. Representative harvest block with plot layout super imposed.

In addition to the plot/percentage method, four other intercept techniques were tried. The first involved random start and random bearing 20 m transects (length to correspond with the existing pre-harvest survey methods). Along the transect, each noticeable microsite was tallied with the corresponding intercept length along the transect. Once the 20 m mark was reached, the line was secured, and two additional 20 m transects were attached each at 60 degrees interior angle to the first to form an equilateral triangle (see Figure 7). The 'turn' to the left or right between the first and second transect was decided by a coin toss to reduce directional bias. Implementation of this design actually allows for the analysis of two designs – the 20 m transects by themselves, and a cluster sample of three, 20 m transects. After the first triangle was completed, a new random start point and bearing were chosen for the next sample cluster.

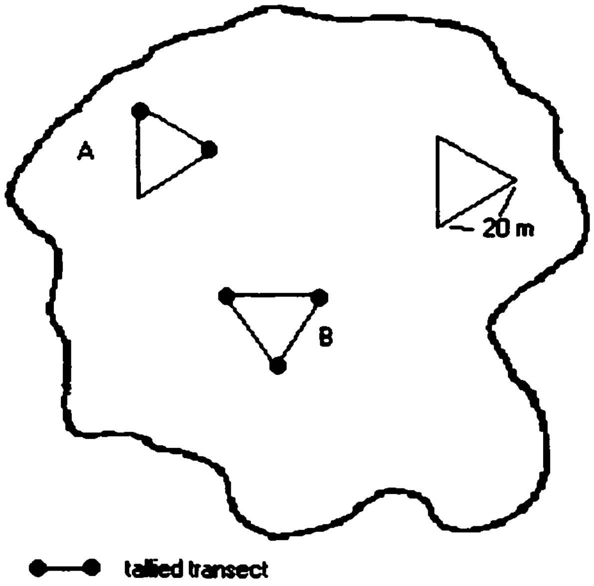

Figure 7. Representative harvest block with transect (A) and triangle (B) layouts super imposed.

The third and fourth transect/intersect methods were completed to satisfy industrial convention. Each of the candidate blocks had an 'X' superimposed at approximately 45 degrees to the main landing. Continuously along the transect, each noticeable microsite was tallied with the corresponding intercept length along the transect. One situation treated each side of the X as two separate transects, the other treated the X as one entire sample unit (see Figure 8). These methods did not have a random start and random direction.

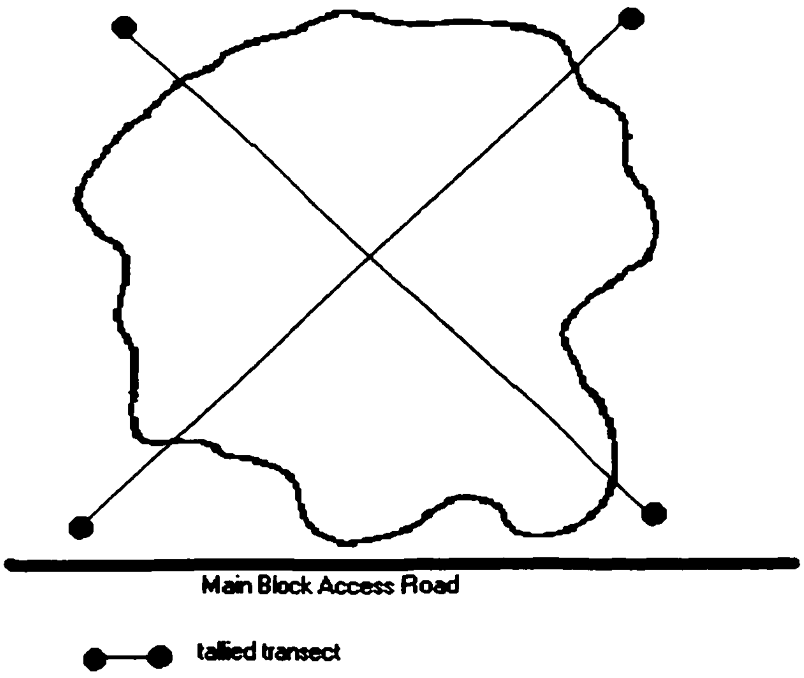

Figure 8. Representative harvest block with conventional X-pattern layout super imposed.

Computer simulations using bootstrapping resampling techniques were used to analyze the data from the recently harvested candidate locations. This gave better approximations of the population (Murchison 1984) as opposed to using only the raw data, leading to a better selection of a sampling technique. The raw data from each of the three methods were pooled by sampling design. The simulator would extract a subsample of n-1 units with replacement, and calculate the mean and variance for each of the microsites. The process was completed again, this time giving a sub-estimate of the population using the mean and variance from the two sub-samples. After completing the third sub-sample, a calculation was done to test if the overall population estimates were improved greater than user defined allowances. If the total population estimates for mean and variance did not exceed the user defined allowances, the simulator would stop. If not the simulator would continue with sub-sampling until the user defined allowances were reached or 2000 cycles, whichever came first. This process was repeated for n-x sub-sample units (where x is the whole number which when entered would give a sub-sample number divisible by 5, for instance 133 – 3 = 130) and so on until a subsample of five units per cycle was selected. This was completed for both 95 and 99% levels of confidence.

The second part of the field survey involved going to areas that were historically harvested under the same conditions (lowland sites harvested in unfrozen conditions). Only observations and notes were made since variations of the natural regeneration would not be quantitatively analyzed. Instead, these observations become useful in applying positive or negative values to microsites with respect to forest regeneration.

RESULTS

In the initial stages of the field surveys, matrices were developed for this specific area of natural and man-made microsite conditions that could occur on the various soils types. To show a collection of the possible microsites in the PFPC limits versus all Manitoba FEC soil classes (Zoladeski *et al.* 1995), refer to Figures 9 and 10. These matrices were developed by going out to different soil types both pre-harvest and post-harvest, walking the entire pre- or post-harvest block noting the types of microsites that could possibly occur. At this point there was no attempt to quantify on a block-by-block basis, only to qualitatively describe which types of microsites are likely to occur on each soil type available.

At this point in the study, upon consultation with the primary project partners and advisors, it was decided that development of a sample system to cover all possible soil types and scenarios would be impractical. The Manitoba soil type S12S (deep organic) was selected due to its fragile nature when harvested in unfrozen conditions. Recent economic, technological, and operational considerations, such as single-grip harvesters and forwarders (see Figures 11 and 12), have made this soil type operable in non-frozen harvest seasons.

	Manitoba F.E.C. Deep Soil Type												
Microsite (Natural)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12F	S12S
Rock Outcrop													
Lichen on Bedrock													
Surface Stoniness													
Gravel													
Exposed Mineral Soil													
Periodic Flooding													
Open Water													
Natural Mounding (top)													
Natural Mounding (mid-slope)													
Natural Mounding (bottom)													
Fine Woody Debris (diam <1cm)													
Coarse Woody Debris													
Decayed Woody Debris													
Exposed Stumps and Roots													
Charcoal													
Herbaceous Cover													
Shrub Cover													
Vegetative Litter													
Timber Regeneration													
Mature Timber (>15yrs)													
Snags													
Wildlife Scat													
Wildlife Use													
Wildlife Trail													
Insect Use													

	Manitoba F.E.C. Deep Soil Type												
Microsite (Harvest Practices)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12F	S12S
Road Bed													
Skidways													
Fine Woody Debris													
Coarse Woody Debris													
Compacted Slash													
Organic Mat Disturbance													
Harvest Rutting (top)													
Harvest Rutting (mid-slope)													
Harvest Rutting (bottom)													
Sawdust/Saw Kerf													
Site Preparation													
Human Litter													
Slash / Prescribed Burn Remnants													
Planted / Seeded Regeneration													

Figure 9. Deep soil matrix – microsites vs. Manitoba Forest Ecosystem Classification (FEC) deep soil types (Zoladeski *et al.* 1995).

	Manitoba F.E.C. Shallow Soil Type								
Microsite (Natural)	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9
Rock Outcrop									
Lichen on Bedrock									
Surface Stoniness									
Gravel									
Exposed Mineral Soil									
Periodic Flooding									
Open Water									
Natural Mounding (top)									
Natural Mounding (mid-slope)									
Natural Mounding (bottom)									
Fine Woody Debris (diam <1cm)									
Coarse Woody Debris									
Decayed Woody Debris									
Exposed Stumps and Roots									
Charcoal									
Herbaceous Cover									
Shrub Cover									
Vegetative Litter									
Timber Regeneration									
Mature Timber (>15yrs)									
Snags									
Wildlife Scat									
Wildlife Use									
Wildlife Trail									
Insect Use									

	Manitoba F.E.C. Shallow Soil Type								
Microsite (Harvest Practices)	SS1	SS2	SS3	SS4	SS5	SS6	SS7	SS8	SS9
Road Bed									
Skidways									
Fine Woody Debris									
Coarse Woody Debris									
Compacted Slash									
Organic Mat Disturbance									
Harvest Rutting (top)									
Harvest Rutting (mid-slope)									
Harvest Rutting (bottom)									
Sawdust/Saw Kerf									
Site Preparation									
Human Litter									
Slash / Prescribed Burn Remnants									
Planted / Seeded Regeneration									

Figure 10. Shallow soil matrix – microsites vs. Manitoba Forest Ecosystem Classification (FEC) shallow soil types (Zoladeski *et al.* 1995).

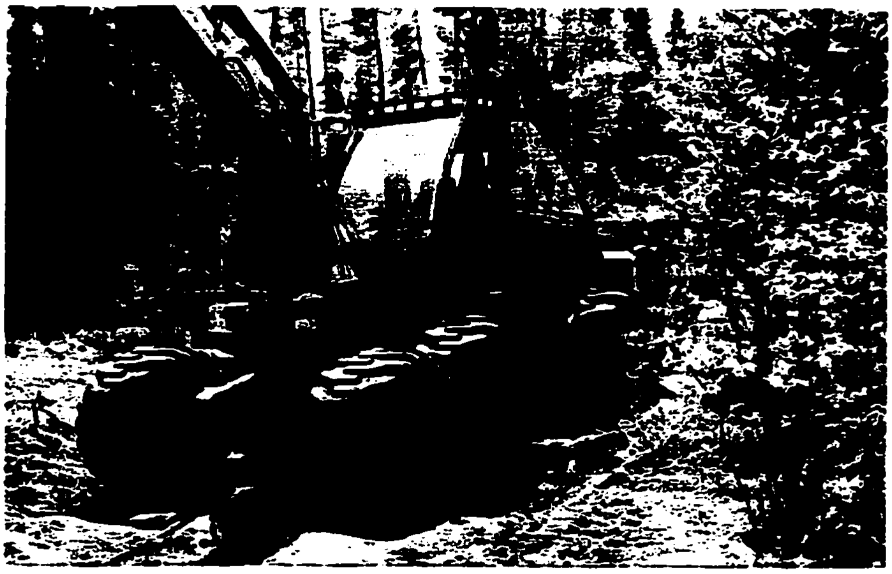

Figure 11. Single-grip harvester type used by PFPC (tracks removed).

Figure 12. Forwarder type used by PFPC (tracks removed).

After purposive sampling, the soil matrix in Figure 13 was found for the S12S type - the shaded areas indicate microsite conditions that occurred on that soil type.

	Manitoba F.E.C. Deep Soil Type												
Microsite (Natural)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12F	S12S
Rock Outcrop													
Lichen on Bedrock													
Surface Stoniness													
Gravel													
Exposed Mineral Soil													
Periodic Flooding													■
Open Water													
Natural Mounding (top)													■
Natural Mounding (mid-slope)													■
Natural Mounding (bottom)													■
Fine Woody Debris (diam <1cm)													
Coarse Woody Debris													■
Decayed Woody Debris													■
Exposed Stumps and Roots													
Charcoal													
Herbaceous Cover													
Shrub Cover													
Vegetative Litter													■
Timber Regeneration													■
Mature Timber (>15yrs)													■
Snags													■
Wildlife Scat													■
Wildlife Use													■
Wildlife Trail													
Insect Use													■

	Manitoba F.E.C. Deep Soil Type												
Microsite (Harvest Practices)	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12F	S12S
Road Bed													
Skidways													■
Fine Woody Debris													■
Coarse Woody Debris													■
Compacted Slash													■
Organic Mat Disturbance													■
Harvest Rutting (top)													■
Harvest Rutting (mid-slope)													■
Harvest Rutting (bottom)													■
Sawdust/Saw Kerf													
Site Preparation													
Human Litter													
Slash / Prescribed Burn Remnants													
Planted / Seeded Regeneration													

Figure 13. Microsite incident matrix for the S12S (Manitoba FEC) soil type.

The goal after developing a matrix of possible site conditions (from herein known as microsites) on the soil type was to assess and propose a sample design to quantify the area of each microsite on a harvested land mass. Using the plot – grid, the transect, and the clustered transect (triangle) techniques described in the methodology of this report, the data shown in Appendices I and II were tabulated.

The bootstrapping simulator technique was applied against the raw data. Table 11 describes the bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error according to the bootstrap simulator for commonly occurring microsites. Microsites were deemed 'common' if their true sampled (not bootstrap simulated) mean exceeded one percent of the plot area.

Table 11. Plot method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error from the bootstrap simulator for commonly occurring microsites. (Plot area = 1 m^2, n = 133 per cycle with replacement repeated until change in S.E. <0.000 001).

Microsite Name	Microsite Code	Desired Confidence (%)	Desired Allowable Error of Mean (%)	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Bootstrap Required Sample Size (#)
Slash Accumulation/ Compaction	67	95	5	22.846	4.4642	70
		95	10	23.457	6.3714	35
		95	15	22.906	7.4238	25
		99	5	23.122	9.9681	90
		99	10	23.108	5.5978	47
		99	15	22.919	6.7932	35
Rutting with organic mat undisturbed depth < 10 cm	57-0	95	5	12.801	2.9074	87
		95	10	13.228	4.0132	45
		95	15	13.166	4.8414	32
		99	5	13.276	2.6002	111
		99	10	13.296	3.6347	59
		99	15	13.014	4.2030	40
Apparent Undisturbed	68	95	5	45.751	6.5527	40
		95	10	46.904	9.2778	20
		95	15	46.688	10.6188	15
		99	5	46.988	5.8938	50
		99	10	47.228	8.3090	27
		99	15	46.730	9.1932	21

Table 12. Transect method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error from the bootstrap simulator for commonly occurring microsites (Transect length = 20 m, n = 131 per cycle with replacement repeated until change in S.E. < 0.000 001).

Microsite Description	Microsite Code	Desired Confidence (%)	Desired Allowable Error of Mean (%)	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Bootstrap Required Sample Size (#)
Slash Accumulation/ Compaction	67	95	5	23.554	2.8077	26
		95	10	23.610	3.6112	15
		95	15	23.667	4.4223	11
		99	5	23.564	2.3914	35
		99	10	23.723	3.1662	20
		99	15	23.716	2.8714	25
Apparent Undisturbed	68	95	5	59.717	5.5638	20
		95	10	59.635	4.5822	30
		95	15	59.864	4.2235	38
		99	5	60.019	4.9051	25
		99	10	59.517	5.6199	37
		99	15	59.983	2.2044	247
Rutting with organic mat undisturbed depth < 10 cm	57-0	95	5	6.285	1.2164	65
		95	10	6.380	1.7534	33
		95	15	6.355	2.0876	23
		99	5	6.298	1.0940	85
		99	10	6.319	1.5311	44
		99	15	6.381	1.7712	30
Rutting, depth 10-20 cm	57-2	95	5	1.363	0.3857	138
		95	10	1.367	0.5229	73
		95	15	1.376	0.6103	50
		99	5	1.311	0.3792	245
		99	10	1.336	0.4594	93
		99	15	1.525	0.5737	65
Rutting, with water present depth 10-20 cm	57-7	95	5	4.461	0.8894	70
		95	10	4.389	1.1519	44
		95	15	4.539	1.4687	25
		99	5	4.556	0.7897	90
		99	10	4.381	1.0783	49
		99	15	4.680	1.3635	35
Rutting, with water present depth 20-30 cm	57-8	95	5	1.426	0.3081	80
		95	10	1.453	0.4630	48
		95	15	1.465	0.5044	30
		99	5	1.476	0.2747	105
		99	10	1.416	0.3653	55
		99	15	1.449	0.4649	39

Table 13. Triangle method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error from the bootstrap simulator for commonly occurring microsites (Total triangle length = 60 m, n = 43).

Microsite Description	Microsite Code	Desired Confidence (%)	Desired Allowable Error of Mean (%)	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Bootstrap Required Sample Size (#)
Slash Accumulation/ Compaction	67	95	5	24.359	2.7383	40
	67	95	10	24.378	1.8884	40
	67	95	15	24.460	2.2659	30
	67	99	5	24.402	2.7853	20
	67	99	10	24.502	3.7871	20
	67	99	15	24.316	5.2426	74
Apparent Undisturbed	68	95	5	59.632	5.1708	20
	68	95	10	59.137	4.0836	37
	68	95	15	59.282	4.7623	25
	68	99	5	59.519	4.3178	30
	68	99	10	59.249	7.3453	111
	68	99	15	59.917	9.2271	210
Rutting with organic mat undisturbed, depth < 10cm	57-0	95	5	6.367	1.5153	43
	57-0	95	10	6.351	2.1836	24
	57-0	95	15	6.527	2.5658	16
	57-0	99	5	6.262	1.4962	72
	57-0	99	10	6.258	1.7741	30
	57-0	99	15	6.306	2.1837	21
Rutting, depth 10-20 cm	57-2	95	5	1.105	0.7583	49
	57-2	95	10	1.093	0.4859	41
	57-2	95	15	1.200	0.6312	27
	57-2	99	5	1.073	0.4580	240
	57-2	99	10	1.080	0.4670	65
	57-2	99	15	1.078	0.5172	39
Rutting, with water present depth 10-20 cm	57-7	95	5	4.719	1.7413	16
	57-7	95	10	4.741	1.5190	23
	57-7	95	15	4.686	1.7566	16
	57-7	99	5	4.904	1.0370	61
	57-7	99	10	4.723	1.2428	30
	57-7	99	15	4.763	1.5132	20
Rutting, with water present depth 20-30 cm	57-8	95	5	1.581	0.4566	62
	57-8	95	10	1.530	0.5654	29
	57-8	95	15	1.544	0.7391	20
	57-8	99	5	1.628	0.4383	95
	57-8	99	10	1.552	0.4889	36
	57-8	99	15	1.631	0.5865	25

Table 13. (Continued)

Rutting, with water present	57-9	95	5	0.923	0.8242	83
	57-9	95	10	0.973	0.5290	72
	57-9	99	15	0.931	0.5386	63
	57-9	99	5	0.925	0.5195	174
	57-9	99	10	0.937	0.5235	121
	57-9	99	15	0.931	0.5386	63

Table 14. Plot method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error of the mean estimate according to the bootstrap simulator for highlighted, rarely occurring microsites (Plot area = 1 m^2, n = 133).

Microsite Name	Microsite Code	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Estimated Sampling Requirement (#) with allowable error of the mean estimate of...:			
				20%	15%	10%	5%
Rutting, top of mound adjacent to depression	55	0.5185	0.32996	64	114	256	1026
Rutting, mid-slope north aspect	56N	0.1518	0.09506	65	115	259	1036
Rutting, mid-slope south aspect	56S	0.2276	0.12192	89	157	354	1417
Rutting, unclassified depth	57	1.9782	0.93038	116	206	463	1851
Rutting, organic mat disturbance, depth 0-10 cm	57-1	1.7835	0.98412	83	148	331	1335
Rutting, depth 10-20 cm	57-2	2.1664	1.05229	110	195	439	1755
Rutting, depth 20-30 cm	57-3	1.4849	0.85500	80	142	318	1274
Rutting, depth 30-40 cm	57-4	0.3846	0.29542	43	76	170	680
Rutting, with water present depth 10-20 cm	57-7	2.8142	1.09947	165	293	660	2640
Rutting, with water present, depth 20-30 cm	57-8	0.7485	0.34614	124	221	498	1996
Rutting with water present, depth > 30 cm	57-9	0.9830	0.50868	97	172	388	1550
Natural Periodic Flooding	7	0.3723	0.28324	43	77	73	691
Natural Mounding	11	1.3441	0.56919	143	255	574	2295
Exposed Stumps and Roots	52	0.4526	0.17629	167	297	669	2676
Rutting, Standing Water	58	0.8177	0.49030	72	129	290	1159

Table 14. (Continued)

Rutting, standing water > 30 cm	58-9	0.5051	0.36341	50	89	200	798
Rutting with periodic flooding	59	0.2907	0.19575	57	101	288	912

Table 15. Transect method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error of the mean estimate from the bootstrap simulator for highlighted, rarely occurring microsites (Transect length = 20 m, n = 131).

Microsite Name	Microsite Code	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Estimated Sampling Requirement (#) with allowable error of the mean estimate of...:			
				20%	15%	10%	5%
Rutting, organic mat disturbance, depth 0-10 cm	57-1	0.630	0.1809	143	254	571	2286
Natural Periodic Flooding	7	0.191	0.0819	171	304	684	2736
Natural Mounding	11	0.227	0.0893	307	546	1229	4917

Table 16. Triangle method bootstrapped means, standard errors, and required sample size to estimate the mean within a user defined allowable error of the mean estimate from the bootstrap simulator for highlighted, rarely occurring microsites (Total triangle length = 60 m, n = 43).

Microsite Name	Microsite Code	Bootstrap Mean (% Coverage of Plot)	Bootstrap S. E. (% Coverage of Plot)	Maximum Estimated Sampling Requirement (#) with allowable error of the mean estimate of...:			
				20%	15%	10%	5%
Rutting, organic mat disturbance, depth 0-10 cm	57-1	0.623	0.31199	250	444	998	3993
Natural Periodic Flooding	7	0.191	0.11894	151	268	603	2400
Natural Mounding	11	0.191	0.11894	151	268	603	2400

Tables 17 and 18 present the results from the conventional large transect methods that were suggested by the funding agency. Table 17 treats each of the diagonal transects as a separate sample unit; whereas, Table 18 combines the two transects into one sample unit per block.

Table 17. Field results from the Diagonal Transect Method.

Block	Transect Number	Microsite Code	Code Length (m)	Total Length (m)	Microsite Area (% of transect length
G1	1	Rutted	67	310	21.6
G1	1	Other	243	310	78.3
G1	2	Rutted	42	310	13.5
G1	2	Other	268	310	86.4
G2	3	Rutted	11	80	13.8
G2	3	Other	69	80	86.2
G2	4	Rutted	16	80	20
G2	4	Other	64	80	80

Table 18. Field results from the X-Pattern Method.

Block	Cluster Number	Microsite Code	Code Length (m)	Total Length (m)	Microsite Area (% of transect length
G1	1	Rutted	109	620	17.58
G1	1	Other	511	620	82.42
G2	2	Rutted	27	160	16.88
G2	2	Other	133	160	83.12

Table 19 summarizes the confidence limits for all design systems for commonly occurring microsites. Table 20 summarizes some of the statistical characteristics of each system such as randomness traits and microsites found. Table 20 also depicts operational implementation considerations including number of personnel to properly implement the system, as well as some qualitative comparisons of each system such as relative time per sample unit and tendencies of the system towards bias.

Table 19. 95% Confidence limits for all sample designs for the commonly occurring microsite classes. Plot, triangle, and transect are from Bootstrapping simulations, X-Pattern and Diagonal Transect from field data.

Design	Microsite Code	Microsite Description	Mean (%)	Standard Error (%)	Upper Limit (%) (95% Confidence)	Lower Limit (%) (95% Confidence)
Plot	57-0	Rutting with organic mat undisturbed, depth < 10 cm	13.17	4.841	22.66	3.68
	67	Slash Accumulation / Compaction	23.12	9.968	42.66	3.59
	68	Apparent Undisturbed	46.69	10.619	67.50	25.88
Transect	57-0	Rutting with organic mat undisturbed, depth < 10 cm	6.36	2.088	10.45	2.26
	57-2	Rutting, depth 10-20 cm	1.38	0.610	2.57	0.18
	57-7	Rutting, with water present depth 10-20 cm	4.54	1.469	7.42	1.66
	57-8	Rutting, with water present, depth 20-30 cm	1.47	0.504	2.54	0.48
	67	Slash Accumulation / Compaction	23.67	4.422	32.34	15.00
	68	Apparent Undisturbed	59.52	5.564	70.42	48.61
Triangle	57-0	Rutting with organic mat undisturbed, depth < 10 cm	6.53	2.566	11.72	1.34
	57-2	Rutting, depth 10-20 cm	1.11	0.758	2.64	-0.43

Table 19. (Continued)

	57-7	Rutting, with water present depth 10-20 cm	4.69	1.757	8.24	1.13
	57-8	Rutting, with water present, depth 20-30 cm	1.54	0.739	3.04	0.05
	57-9	Rutting with water present, depth > 30 cm	0.92	0.824	2.59	-0.74 or 0
	67	Slash Accumulation / Compaction	24.32	5.243	34.92	13.72
	68	Apparent Undisturbed	59.92	9.227	78.57	41.26
Large Diagonal Transects	Disturbed	Block G1	17.55	4.05	69.01	-33.91 or 0
	Other	Block G1	82.30	4.05	133.76	30.84
	Disturbed	Block G2	16.90	3.10	56.289	-22.49 or 0
	Other	Block G2	83.1	3.10	122.49	43.71
X-Pattern Single Unit	Disturbed	Block G1		Data	Not	Possible
	Other	Block G1		Data	Not	Possible
	Disturbed	Block G2		Data	Not	Possible
	Other	Block G2		Data	Not	Possible

Table 20. Interpreted qualities of the sample designs.

Quality	Plot Method	Transect Method	Triangle Method	X-Pattern Method	Single Diag. Transects
Degrees of Freedom per Cut Area	133	131	43	0	1
Random Start	Yes	Yes	Yes	No	No
Random Direction	Yes	Yes	Yes	No	No
Number of Different Microsites	20	10	10	2	2
Number of Crew Members to Properly Implement	1 or 2	2	2	2	2
Relative Time Per Sample Unit	High	Med.	Med.	Low	Low
Relative Possibility of Directional Bias Influencing Data	Low	High	Med.	High	High

DISCUSSION

LITERATURE COMPARISON

Practical experience has shown that to eliminate soil impact is virtually impossible without excessive and unbearable costs to the procurement company and thus passed on the consumer of wood products. Many studies such as Mellgren and Heidersdorf (1984), Novak (1988), and Gingras *et al.* (1991) to name a few have made contributions as to the type of machinery used for harvesting and the steps pre-harvest planning without making cost-prohibitive changes to operations.

Studies such as Hakansson and Voorhees 1997 and Archibald 1997 have contributed in certain contexts, to the pre-harvest planning stages by bringing to attention the different hazards of soil impact associated with different soil textures and types. Dyrness (1965), Bockheim *et al.* (1975), and up to Sidle and Drlica (1981) began to work on sample designs to assess the impact from forest harvesting.

Up to this point, there is little in the literature to suggest a rigid, statistically justified approach to assess a particular harvest block for soil impact. This thesis has taken these studies and others a step further in an unprecedented context where an actual sample design (method to collect the information) is evaluated for a particular boreal forest soil. The three unconventional methods presented are repeatable, statistically justifiable (that is they meet statistical objectives), and could be implemented by the forest manager in an operations setting. Additionally, these sample designs can be implemented to meet the criteria of the CCFM (1997a). The two more conventional intercept methods of large block bi-section have a weaker possibility to be used to meet CCFM (1997a) criteria and were completed more to satisfy industry convention.

THE PLOT METHOD

From the results presented in the previous section, the plot method seems to be the 'benchmark' of comparison for the other methods. Twenty different microsites were tallied with only three commonly occurring. Those sites included the Apparent Undisturbed (microsite code 68), the Slash Accumulation/Compaction (microsite code 67) and Rutting <10 cm with Undisturbed Organic Mat (microsite code 57-0) microsite classes totaling mean values approaching 83% of the harvest block (Table 11). To assess these candidate blocks with 95% confidence and 5% allowable error of the mean, up to 87 plots would be required, 111 for 99% confidence and 5% allowable error (Table 11).

A very apparent characteristic of the plot method is the ability to provide a more detailed description of the harvested area as compared to the other data collection systems. Table 20 indicates that the plot method found 20 different microsite classes, the unconventional intercept techniques presented 10. The conventional large transect by default of their Boolean design only found two microsite descriptions, disturbed and undisturbed. This difference can be attributed to the design itself forcing the surveyor to stop travel through the harvested block and focus almost entirely on a one square metre area. With line intercept triangle and transect methods, the data is collected while the surveyor is traveling and can be easily distracted by orientation or difficulty with terrain.

The detail of the plot data collection method does not however come without certain costs associated with it. Although a complete benefit-cost analysis was not completed for any of the methods associated with this study, the plot method generally took more time than the others to complete the data collection for the candidate harvest blocks and more sample units are required per sample area. The additional detail also adds variance to the data set and increases the number of sample units required to obtain satisfactory statistical estimates as can be seen in Table 11. For example to estimate the slash accumulation (microsite code 67) with 95% confidence and 5% allowable error of the mean, a total of 70 sample units were required to accurately estimate the mean using the plot method (Table 11). The transect method required 26 sample units (Table 12) and the triangle method required 20 sample units (Table 13) for the same microsite and parameters. In general one transect would equal the same amount of time as chaining to, establishing, and surveying two plots. Prima fascia, plot method seems to use more time, a complete time / cost analysis would be beneficial to exemplify this further.

The plot design also shows some promise as a tool for the forest manager to determine the amount of natural regeneration, residual desired species, and area of the harvest block suitable for natural or assisted regeneration. The fact that the system is of such high resolution (being able to pick up many microsites and the variability of the microsite within the harvest area) offers regeneration managers a better profile of the treatment area. During observational tours of areas harvested four to five years previous and eight to ten years previous, it was noticed that areas impacted with rutting greater than a few centimeters and or held water were detrimental to natural, unassisted regeneration. Preferred microsites for natural regeneration included undisturbed areas (provided other vegetative competition was low) and the mounded areas immediately adjacent to rutted zones. Further, more intense study would be able to further enlighten the ability of this system to supply such information and either improve upon or discredit these observations.

Operationally speaking, from the aspects of implementation and compliance with auditing criteria, there are positive and negative aspects to a plot sample design. The system offers the information requested by the CCFM with statistically justifiable and reliable estimates. Statistical bias is identifiable and measurable. In addition, there is the possibility of the field program being implemented with only one person since the travel between sample units and the data gathering are two distinctly different procedures. Strong caution is warranted here - this could only be implemented where it is safe to do so as to not endanger an isolated field employee.

One negative aspect is that the data do come with the cost of increased sampling intensity and higher field time per surveyed harvested block compared to the other methods presented. The resolution of this sample design also adds to the complexity of the data collected by field personnel. Competence of field personnel would be paramount as to not loose resolution within the data.

With the particular sponsoring partners in this instance (PFPC and the MBMF), this method also holds the promise of correlation with the already plot based pre-harvest information gathering procedure. Tying these two surveys together may offer information about ecological transitions of pre and post harvest conditions that now elude forest managers. After more extensive data collections, modeling predictions may develop giving confident estimates of post-harvest amelioration and regeneration requirements from pre-harvest information. Continuing along this line, further conforming with plot based regeneration surveys could also be possible. This better enables the forest manager to properly pre-plan allocation of resources where required. Inherently overall survey costs would also be reduced having two or three harmonized sampling procedures working in conjunction rather than distinct and unrelatable data collection systems.

THE TRANSECT AND TRIANGLE METHODS

In addition to the plot method, the transect and to a lesser degree triangle methods show promise to satisfy the CCFM auditing criteria. There is some difference between the intercept methods and the plot method in terms of means for individual microsites. Additionally, the intercept methods only detected ten different microsites, but these transect-based designs were completed with only one crewmember.

During the plot method, the surveyor compasses and chains to a location, installs the plot, and is allowed to concentrate on the plot contents. With the intercept methods, the surveyor is attempting to compass and distance him/herself all the while trying to identify and measure the intercept length of microsites simultaneously. It can be hypothesized that possible surveyor error may have been reduced if funding and timelines allowed for an increase in crew size. As well, separate trials for the transect and triangle designs may have offered better comparisons rather than the overlapped data collected here (the triangle design was a clustered version of the transect method). Again, temporal and budgetary constraints did not allow for separate trials due to limits imposed by the funding agencies.

Possibly due to an error in the collection process or due to the larger area encompassed in the sample unit, the intercept methods have lower standard errors. This leads to lower required number of sample units to gather the required data. For example, reviewing the data for the slash accumulation/compaction (microsite code 67) to measure the mean to within 5% with 95% confidence, only 26 sample units are required using the transect method (Table 12) compared to the 70 sample units of the plot method (Table 11). The triangle method did not see a large improvement over the transect design method in this instance requiring 20 sample units (Table 13). Even though the sample unit of the triangle method is 300% the size of the transect method sample unit, there is only a 20% gain in improvement of sample units required to accurately estimate the mean for this microsite.

A word of caution is warranted here. There is no indication if the lesser number of sample units compared to the plot method is due to the sample design itself or due to the lower sample variance brought on by using only one crew member with this method. The intercept methods would then seem to be favoured over the plot method. However there are some inherent problems with the transect and triangle methods that are not clearly evident in the statistical values such as the resolution of the sample design to detect certain, possibly important microsites (see Table 20).

Operationally speaking, at first glance, the triangle and transect methods would seem feasible. They have random start, random direction, and more than 2 degrees of freedom given that more than 3 transects or triangles would be implemented in each block. The transect method does pose the threat of biasing the data in that there is a chance that a sample unit (transect line) may follow along a single microsite type (such as a wheel rut) for an extended length. This would skew the data in favor of that microsite code. This could be handled by using multi-directional transects, like the triangle design or a circular design, or by implementing rules of omission during data collection. These 'rules' would have to be developed with extreme caution however since a known bias would be introduced.

From an auditor's standpoint, the data collected in the transect system are repeatable, statistically justifiable and has clear means to judge accuracy. A possible drawback would be the potential for missing or mis-measuring microsites since travel and data collection occur in the same phase. This may be overcome with additional crew members.

These two sample designs do not offer the direct integration adaptability that the plot does to the pre-harvest and post-harvest systems that are already in use by the funding agencies. The pre-harvest surveys already in place use a non-fixed area plot for timber analysis with a fixed area nested vegetative plot at sample unit centre to monitor pre-harvest vegetative components. The post-harvest regeneration plots are fixed area. Integration of a transect-based post-harvest assessment system would prove difficult and could eventually increase long-term financial costs.

THE X-PATTERN AND DIAGONAL TRANSECT METHODS

These methods are different from the other methods based on its prime development premise. Whereas the other systems were assessed for their statistical and implementation merit, these methods were studied to assess the efficacy of execution to satisfy CCFM auditing criteria and to satisfy industrial convention.

Both the X-Pattern system where two large diagonal transects are treated as one large sample unit, and the Large Diagonal Transects which has two sample units comprised of single transects, appear to be the least favorable of all the systems studied.

Although very easy to implement from an operations standpoint, there are questions of the applicability and accuracy of the data.

The results displayed in Table 20 clearly indicated that a substantial amount of information is lost in the X pattern or single large transect design over the other systems. This design attempts only to quantify rutted area versus non-rutted area. Lacking are other microsite delineations such as areas suitable for natural regeneration, and areas suitable for assisted regeneration.

In the two large transect design (where number of sample units is two), there is no random start or bearing. Under these circumstances, statistical analysis is inappropriate. However, if traditional statistical analysis were applied, there would only be one degree of freedom (n-1 = 1) leading to extremely high variance estimators. For instance, looking at the disturbed areas for the two large transects in Block G1 (see Table 17), the percent of the intercept for the disturbed and undisturbed codes on each transect was 21.6% and 13.5% respectively. This small data set has a mean of 17.55% and a standard error of the mean of 4.05%. The 95% confidence interval for the disturbed area of this transect would then be between –33.91% (which is impossible and thus assumed to be 0) and 69.01%. To interpret, using this method and treating each side of the X as two separate sample units, with 95% confidence we can say that between zero and almost 70 percent of the sample unit has been impacted by harvest. The non-random start may introduce a difficult to detect and quantify bias. Additionally, having these two transects cross introduces an unknown covariance term at the intersection point. The statistical results presented for these methods were completed to enhance the discussion of these sampling methods and may only be applied to this particular study.

Treating the X as a single sample unit yields slightly different and as unreliable results. Again, with this method, statistical analysis is inappropriate. Also, there is only one sample unit per sample area, there are no degrees of freedom. The problem here is that there is no way to determine bias, standard error, or required sample size. Any bias of the sample design is undetectable and unmeasureable making the accuracy of collected information questionable. As with the two large crossing transect design the scope of inference may not be projected beyond the sample unit.

Essentially, the application of these particular designs would provide no useful and supported data. In a CCFM audit scenario, the organization applying the system would leave them open to intense and possibly detrimental scrutiny. In addition to this, although there is some indication of the level of disturbance, there is no measure of detrimental, neutral, and beneficial disturbance. These sample designs also face the same integration problems into present operations of the transect and triangle designs.

CONCLUSIONS AND RECOMMENDATIONS

The results and discussions presented here indicate use of large transect intercept systems would not prove favorable in a statistical, informational, or conclusive auditing forum. With no measure of reliability, these designs merely give a binomial survey of presence or absence of impact with no measure of error.

The most favorable method investigated in this example was the use of plots. Although standard errors and thus required sample sizes are comparatively higher than for the other methods evaluated, the amount of information gained by a forest manager and an auditing agency outweighs these concerns. In some situations, a total value index including both positive and negative impacts from a harvesting operation on these soil types, might be possible. Increased field costs due to a more intense survey method would have to be carefully controlled to maintain or increase the economic operability of this design.

The multiple intercept methods should not be totally discarded. If problems already discussed could be overcome or quantified, these methods may lead to a more operationally feasible design without sacrificing the quality of information collected. Increasing field crew sizes would greatly enhance the information gained using this design. However, advanced pre-harvest and post-harvest correlation values may be lost with this methodology if there is no effort to harmonize this with existing pre-harvest plot based designs.

In closing, advanced studies should focus on further qualifying these systems and assessing the impact of different microsites on forest regeneration. Attention should also be paid to determining if these systems can be implemented on other forest soil types in other geographic regions. Integration with pre-harvest assessment systems may also prove fruitful in giving the forest manager information to properly assess management options.

For the particular S12S sites studied, the 1m^2 plot design proved to be the most efficient to estimate the impact of forest operations. This design gave the highest resolution of information and although a thorough cost analysis was not completed, may prove to be the most economically efficient. The application of this design to the S12S sites did produce higher standard errors of the estimates. Despite this it is recommended that this design be used under similar conditions due to the greater amount of information collected over the alternate designs tested.

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APPENDICES

APPENDIX I

FIELD COLLECTED PLOT DATA

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
1	68	100	*Sphagnum spp.*	40		
			Ledum groenlandicum	70		
			Grass	20		
2	57-2	20	*Sphagnum spp.*	40		
2	68	80	*Ledum groenlandicum*	40		
			F.W.D.	20		
			Sphagnum spp.	90		
3	68	100	*Alnus crispa*	10		
			Carex spp.	30		
			C.W.D.	20		
			F.W.D.	10		
			Sphagnum spp.	30		
4	68	100	F.W.D.	40		
			Equisetum sylvaticum	10		
			Sphagnum spp.	20		
			Grass	30		
5	57-0	100	Grass	100		
			Sphagnum spp.	10		
6	68	100	*Ledum groenlandicum*	60		
			Grass	10		
			F.W.D.	20		
7	67	100	*Carex spp.*	10		
8	67	100				
9	58-9	60				
9	68	40	C.W.D.	20		
			Ledum groenlandicum	80		
			Sphagnum spp.	40		
10	57	20	*Sphagnum spp.*	40		
10	68	80	*Ledum groenlandicum*	20		
			Sphagnum spp.	40		
			Grass	20		
			Mitella nuda	20		
11	52	10				
11	67	50				
11	68	40	*Ledum groenlandicum*	20		
			F.W.D.	60		
12	57-1	20	Vegetative Litter	80		
12	67	60	Grass	20		
12	68	20	*Sphagnum spp.*	80		
			Grass	10		
			F.W.D.	30		
13	57-0	20	F.W.D.	20		
			Sphagnum spp.	60		
13	67	20				

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
13	68	60	Grass	20		
			Salix spp.	80		
14	57-8	20	Salix spp.	20		
14	68	80	*Sphagnum spp.*	90		
			Ledum groenlandicum	30		
			Grass	10		
15	68	100	*Alnus crispa*	10		
			Ledum groenlandicum	40		
			Sphagnum spp.	20		
			Grass	20		
			F.W.D.	10		
16	57-0	70	*Alnus crispa*	10		
			Sphagnum spp.	80		
			Ledum groenlandicum	10		
			Grass	10		
16	68	30	Grass	60		
			F.W.D.	20		
17	57-0	100	*Salix spp.*	40		
			Alnus crispa	10		
			C.W.D.	10		
			Sphagnum spp.	30		
			Ledum groenlandicum	20		
			F.W.D.	10		
18	67	100	*Alnus crispa*	10		
19	57-0	40	Vegetative Litter	20		
			Salix spp.	10		
19	68	60	F.W.D.	40		
			Alnus crispa	20		
			Grass	70		
20	67	100	Grass	20		
21	68	100	*Ledum groenlandicum*	20		
			Grass	80		
			Sphagnum spp.	10		
22	11	20	Water	80		
			Sphagnum spp.	10		
			Alnus crispa	10		
22	68	80	*Ledum groenlandicum*	20		
			Grass	80		
23	57-9	50				
23	68	50	*Ledum groenlandicum*	40		
			F.W.D.	10		
			Sphagnum spp.	20		
			C.W.D.	30		
24	68	100	*Ledum groenlandicum*	50		
			C.W.D.	10		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
			F.W.D.	10		
			Sphagnum spp.	40		
25	57-0	100	*Alnus crispa*	50		
			Vegetative Litter	50		
			Salix spp.	10		
			F.W.D.	20		
			C.W.D.	10		
26	57-0	40	*Sphagnum spp.*	100		
			Smilacina trifolia	20		
			Salix spp.	10		
			Alnus crispa	10		
26	68	60	*Alnus crispa*	40		
			Salix spp.	20		
			Sphagnum spp.	90		
27	67	100	*Dicranum spp.*	10		
28	11	10	Grass	10		
			Water	90		
28	68	90	*Alnus crispa*	70		
			F.W.D.	30		
			Grass	10		
29	57-0	100	*Sphagnum spp.*	40		
			Grass	60		
			F.W.D.	10		
			Salix spp.	10		
			Alnus crispa	10		
30	55	30	*Alnus crispa*	30		
			Ledum groenlandicum	20		
			Grass	10		
30	56N	10	Grass	40		
			Equisetum sylvaticum	10		
			Ledum groenlandicum	10		
30	56S	10	*Alnus crispa*	10		
			Grass	10		
			Smilacina trifolia	10		
30	57-4	50	*Sphagnum spp.*	40		
			Grass	40		
31	52	10				
31	57-0	30	*Sphagnum spp.*	70		
			F.W.D.	30		
			Grass	10		
31	68	60	*Sphagnum spp.*	60		
			F.W.D.	40		
			Ledum groenlandicum	10		
32	68	100	F.W.D.	20	BS	1
			Grass	60		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
			Ledum groenlandicum	40		
33	56S	10	*Sphagnum spp.*	90		
			Ledum groenlandicum	10		
33	57-9	10				
33	68	80	*Sphagnum spp.*	90		
			Ledum groenlandicum	30		
			Grass	10		
34	68	100	*Alnus crispa*	80		
			C.W.D.	10		
			Ledum groenlandicum	20		
			Grass	10		
35	57-8	30	Vegetative Litter	50		
35	68	70	*Alnus crispa*	10		
			F.W.D.	20		
			Salix spp.	10		
			Grass	40		
			Sphagnum spp.	40		
36	57-0	40	F.W.D.	30		
			Sphagnum spp.	20		
36	67	60	Grass	10		
37	57-0	60	Grass	20		
			Ledum groenlandicum	20		
			Sphagnum spp.	80		
37	68	40	*Sphagnum spp.*	100		
			Ledum groenlandicum	20		
			Grass	10		
38	57-3	70	F.W.D.	100		
38	68	30	F.W.D.	30		
			Sphagnum spp.	20		
			Salix spp.	10		
39	57-0	40	Grass	30		
			F.W.D.	20		
39	57-7	50	F.W.D.	90		
39	68	10	Grass	40		
			Sphagnum spp.	20		
			Chamaedaphne calyculata	20		
40	68	100	*Sphagnum spp.*	100		
41	57-0	20	*Salix spp.*	20		
			Grass	10		
			Ledum groenlandicum	30		
41	57-8	10				
41	68	70	*Salix spp.*	40		
			Ledum groenlandicum	40		
			Grass	20		
42	67	100				

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
43	67	40	Grass	20		
43	68	60	*Alnus crispa*	20		
			Sphagnum spp.	80		
			Grass	10		
			Ledum groenlandicum	20		
44	57-3	100	*Ledum groenlandicum*	30		
			Water	20		
			Salix spp.	40		
45	68	100	*Salix spp.*	20		
			Ledum groenlandicum	40		
			Grass	40		
			Sphagnum spp.	10		
			F.W.D.	30		
46	68	100	Alnus crispa	20		
			Ledum groenlandicum	30		
			Grass	30		
			Sphagnum spp.	20		
47	57-0	30	*Ledum groenlandicum*	30		
			Sphagnum spp.	10		
			Alnus crispa	10		
47	67	30				
47	68	40	F.W.D.	60		
			Ledum groenlandicum	20		
48	57-0	20	C.W.D.	60		
			F.W.D.	20		
			Grass	20		
48	57-7	10	Water	80		
			Grass	10		
			Alnus crispa	10		
48	68	70	C.W.D.	70		
			F.W.D.	20		
			Grass	30		
			Salix spp.	20		
49	57-0	30	C.W.D.	90		
			F.W.D.	10		
49	67	70				
50	57-0	70	C.W.D.	70		
			F.W.D.	20		
			Alnus crispa	10		
50	68	30	Grass	10		
			Alnus crispa	10		
			F.W.D.	60		
51	11	10	*Sphagnum spp.*	80		
			Grass	10		
			Ledum groenlandicum	10		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
51	68	90	*Sphagnum spp.*	70		
			Grass	10		
			Alnus crispa	20		
			Ledum groenlandicum	20		
52	68	100	F.W.D.	30		
			Grass	20		
			Rubus pubescens	10		
			Alnus crispa	20		
			Sphagnum spp.	40		
53	52	10	C.W.D.	100		
53	57-9	10				
53	68	80	*Alnus crispa*	20		
			Ledum groenlandicum	20		
			Dicranum spp.	10		
			Grass	30		
54	68	100	Grass	10		
			Alnus crispa	10		
55	57-8	30	*Alnus crispa*	20		
			Grass	10		
55	68	30	F.W.D.	60		
			Grass	20		
56	68	100	*Sphagnum spp.*	10		
			Ledum groenlandicum	20		
			Gaultheria hispidula	10		
57	68	100	C.W.D.	10		
			F.W.D.	30		
			Ledum groenlandicum	30		
			Sphagnum spp.	70		
58	67	100	Grass	10		
59	68	100	Salix spp.	30		
			Alnus crispa	10		
			Grass	20		
			F.W.D.	10		
			Sphagnum spp.	80		
60	57-1	20	Grass	10		
			Sphagnum spp.	30		
60	57-7	80	C.W.D.	90		
			Water	10		
61	57-7	30	*Alnus crispa*	10		
			Grass	10		
61	67	50				
61	68	20	F.W.D.	80		
			Grass	20		
62	57-1	100	F.W.D.	80		
			Sphagnum spp.	10		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
63	7	50	*Alnus crispa*	50		
			Grass	30		
			F.W.D.	10		
63	68	50	*Ledum groenlandicum*	30		
			Grass	30		
			F.W.D.	20		
64	68	100	*Sphagnum spp.*	70	BS	4
			Grass	10		
65	57-1	100	*Ledum groenlandicum*	10		
			F.W.D.	80		
66	68	100	*Salix spp.*	20		
			Ledum groenlandicum	20		
			Sphagnum spp.	70		
67	67	100	*Ledum groenlandicum*	10		
68	57-0	40	*Alnus crispa*	10		
			Ledum groenlandicum	40		
			Grass	10		
			Sphagnum spp.	20		
68	68	60	*Alnus crispa*	20		
			Ledum groenlandicum	40		
			Grass	10		
			Sphagnum spp.	30		
69	57	100	F.W.D.	80		
			Grass	20		
			Rubus idaeus	10		
70	68	100	C.W.D.	60		
			F.W.D.	20		
			Ledum groenlandicum	10		
			Sphagnum spp.	20		
			Grass	10		
71	57-0	40	*Alnus crispa*	20		
			Sphagnum spp.	70		
			Ledum groenlandicum	10		
			F.W.D.	20		
71	67	60	Grass	10		
72	57-7	30	Grass	20		
72	68	70	*Alnus crispa*	10		
			Grass	20		
			Sphagnum spp.	40		
			F.W.D.	10		
			C.W.D.	10		
73	57-7	20	Grass	60		
73	68	80	Grass	30		
			Salix spp.	20		
			Sphagnum spp.	90		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
74	68	100	*Salix spp.*	30		
			Sphagnum spp.	10		
			Grass	20		
			F.W.D.	50		
75	68	100	*Sphagnum spp.*	70		
			Salix spp.	60		
76	57-0	50	F.W.D.	10		
			Sphagnum spp.	100		
			Salix spp.	10		
76	67	50				
77	67	100				
78	52	10				
78	67	70				
78	68	20	*Ledum groenlandicum*	20		
			Sphagnum spp.	90		
			Vaccinium vitis-idaea	10		
79	68	100	*Sphagnum spp.*	100		
			Grass	10		
			Alnus crispa	20		
			Salix spp.	30		
			Ledum groenlandicum	20		
			Gaultheria hispidula	10		
80	57-0	50	*Salix spp.*	20		
			Grass	30		
80	68	50	*Ledum groenlandicum*	20		
			Sphagnum spp.	100		
			Alnus crispa	20		
81	68	100	Grass	20		
			Sphagnum spp.	100		
			Ledum groenlandicum	10		
			F.W.D.	10		
			Gaultheria hispidula	10		
82	57-2	100	C.W.D.	30		
			Grass	10		
			Salix spp.	10		
			Sphagnum spp.	30		
			F.W.D.	20		
			Ledum groenlandicum	10		
83	11	40	F.W.D.	50		
			C.W.D.	10		
			Alnus crispa	10		
			Grass	10		
			Sphagnum spp.	10		
83	68	60	C.W.D.	20		
			F.W.D.	20		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
			Grass	20		
			Ledum groenlandicum	10		
			Sphagnum spp.	10		
84	57-0	50	C.W.D.	10		
			F.W.D.	20		
84	57-7	50	*Alnus crispa*	10		
			Sphagnum spp.	90		
			Rubus pubescens	10		
			Grass	10		
			C.W.D.	10		
85	68	100	F.W.D.	60	BS	1
			C.W.D.	10		
			Grass	10		
			Sphagnum spp.	70		
86	57-0	100	*Salix spp.*	20		
			C.W.D.	10		
			Sphagnum spp.	80		
			Grass	10		
87	11	60	*Salix spp.*	80		
			Alnus crispa	10		
87	68	40	*Ledum groenlandicum*	20		
			Sphagnum spp.	10		
			Salix spp.	40		
			Alnus crispa	20		
			Grass	20		
88	67	100				
89	68	100	*Ledum groenlandicum*	20	BS	3
			C.W.D.	20		
			Grass	20		
			Sphagnum spp.	30		
			Salix spp.	20		
90	57-2	60	C.W.D.	40		
			F.W.D.	60		
			Ledum groenlandicum	10		
90	68	40	*Alnus crispa*	60		
			Sphagnum spp.	20		
			Ledum groenlandicum	10		
			F.W.D.	20		
91	68	100	Grass	60		
			F.W.D.	10		
			Alnus crispa	20		
			Ledum groenlandicum	10		
92	57-0	20	Grass	10		
			Ledum groenlandicum	10		
92	67	80				

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
93	68	100	Grass	20	BS	1
			Sphagnum spp.	100		
			Gaultheria hispidula	10		
			Ledum groenlandicum	20		
			F.W.D.	10		
			Salix spp.	10		
94	57-2	90	Grass	10		
			Sphagnum spp.	90		
95	57-0	100	C.W.D.	30		
			F.W.D.	40		
			Alnus crispa	10		
			Sphagnum spp.	20		
			Grass	10		
96	57-0	40	*Sphagnum spp.*	20		
			Grass	20		
			F.W.D.	40		
			C.W.D.	20		
96	57-2	20	F.W.D.	100		
96	67	30				
96	68	10	Grass	20		
			F.W.D.	40		
97	57-0	100	C.W.D.	10		
			F.W.D.	10		
			Grass	20		
			Sphagnum spp.	20		
			Alnus crispa	30		
98	57-9	50	Grass	60		
98	68	50	C.W.D.	40		
			F.W.D.	20		
			Grass	40		
99	11	20	F.W.D.	100		
99	52	10				
99	68	70	*Ledum groenlandicum*	40		
			F.W.D.	60		
			Grass	20		
			Sphagnum spp.	10		
100	57-0	40	C.W.D.	20		
			F.W.D.	40		
			Grass	20		
100	67	60				
101	57-0	100	C.W.D.	20		
			F.W.D.	20		
			Sphagnum spp.	80		
			Ledum groenlandicum	30		
			Grass	20		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
102	57-0	40	F.W.D.	90		
			Grass	10		
102	67	60				
103	57-7	100	*Sphagnum spp.*	60		
			Grass	10		
104	67	70				
104	68	30	*Salix spp.*	10		
			Grass	10		
			Sphagnum spp.	30		
			F.W.D.	30		
			C.W.D.	20		
105	68	100	*Ledum groenlandicum*	60		
			C.W.D.	20		
			Grass	40		
			Sphagnum spp.	40		
106	68	100	F.W.D.	60		
			Alnus crispa	20		
			C.W.D.	10		
			Ledum groenlandicum	30		
107	57-0	30	*Sphagnum spp.*	90		
			Grass	10		
			F.W.D.	10		
107	68	70	*Ledum groenlandicum*	10		
			Grass	20		
			Salix spp.	30		
			Sphagnum spp.	100		
			F.W.D.	10		
108	57-0	50	*Sphagnum spp.*	80		
			F.W.D.	20		
			Ledum groenlandicum	20		
			Grass	10		
108	57-8	10	*Sphagnum spp.*	10		
108	67	40				
109	11	20	Water	100		
109	68	80	*Alnus crispa*	40		
			Grass	70		
			F.W.D.	10		
			Sphagnum spp.	20		
110	67	100				
111	57	60	C.W.D.	100		
111	58	40				
112	68	100	F.W.D.	10		
			C.W.D.	10		
			Sphagnum spp.	60		
			Equisetum sylvaticum	20		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
			Ledum groenlandicum	20		
113	67	60				
113	68	40	F.W.D.	100		
114	56N	10	*Sphagnum spp.*	40		
			Ledum groenlandicum	10		
114	56S	10	*Pleurozium schreberi*	60		
114	57	50	C.W.D.	50		
			F.W.D.	50		
114	68	30	*Sphagnum spp.*	10	BS	1
115	68	100	F.W.D.	40		
			C.W.D.	30		
			Ledum groenlandicum	10		
			Pleurozium schreberi	10		
116	55	40	*Sphagnum spp.*	40		
			Ledum groenlandicum	20		
116	59	30	*Sphagnum spp.*	80		
116	68	30	*Sphagnum spp.*	50	WB	1
			Ledum groenlandicum	10		
			Alnus crispa	20		
117	68	100	*Sphagnum spp.*	70		
			Ledum groenlandicum	20		
118	58	60	*Alnus crispa*	10		
			C.W.D.	20		
118	68	40	*Sphagnum spp.*	100		
119	67	100				
120	52	10				
120	68	90	Grass	10		
			Sphagnum spp.	80		
			Pleurozium schreberi	10		
			Chamaedaphne calyculata	20		
			Gaultheria hispidula	10		
			Smilacina trifolia	10		
121	67	100				
122	67	90				
122	68	10	*Equisetum sylvaticum*	20		
			Sphagnum spp.	90		
123	67	100				
124	67	100				
125	67	100				
126	68	100	*Sphagnum spp.*	80		
			Ledum groenlandicum	20		
			F.W.D.	20		
127	67	90				
128	68	10	*Sphagnum spp.*	20		
128	68	100	*Sphagnum spp.*	30		

Plot #	Code	Code Area (%)	Non-Timber Components	Component Cover (%)	Regen. Species	Regen #
			Ledum groenlandicum	10		
			C.W.D.	20		
			F.W.D.	10		
			Vegetative Litter	20		
129	57-3	30	*Ledum groenlandicum*	40		
			Sphagnum spp.	30		
			F.W.D.	60		
129	58-9	10				
129	68	60	*Equisetum sylvaticum*	10		
			Sphagnum spp.	60		
			C.W.D.	30		
			F.W.D.	10		
130	57	30	*Equisetum sylvaticum*	10		
			Sphagnum spp.	50		
130	58	10				
130	67	70				
131	67	100	*Equisetum sylvaticum*	20		
132	67	100				
133	59	10				
133	68	90	*Sphagnum spp.*	70		
			Alnus crispa	10		
			Grass	30		
			Ledum groenlandicum	10		
134	67	100				

APPENDIX II

FIELD TRANSECT/TRIANGLE DATA

Triangle	Transect	Code	Total Area (m)	Code Area (%)
1	1	68	33	65
1	1	67	10	20
1	1	57-8	1	3
1	1	57-7	6	13
1	2	57-7	4	8
1	2	57-8	1	3
1	2	67	8	15
1	2	68	23	45
1	2	67	15	30
1	3	67	20	40
1	3	68	30	60
2	1	67	28	55
2	1	57-0	5	10
2	1	57-9	10	20
2	1	57-7	8	15
2	2	67	15	30
2	2	57-0	23	45
2	2	57-8	3	5
2	2	57-7	10	20
2	3	68	35	70
2	3	67	10	20
2	3	57-0	5	10
3	1	67	15	30
3	1	68	30	60
3	1	57-0	5	10
3	2	68	28	55
3	2	67	10	20
3	2	11	3	5
3	2	57-2	10	20
3	3	68	48	95
3	3	7	3	5
4	1	68	35	70
4	1	67	13	25
4	1	57-0	3	5
4	2	68	40	80
4	2	67	5	10
4	2	57-1	5	10
4	3	68	30	60
4	3	67	13	25
4	3	57-0	5	10
4	3	57-2	3	5
5	1	68	23	45
5	1	57-7	13	25
5	1	67	15	30

Triangle	Transect	Code	Total Area (m)	Code Area (%)
5	2	68	20	40
5	2	57-0	5	10
5	2	57-2	5	10
5	2	57-8	3	5
5	2	67	15	30
5	2	57-7	3	5
5	3	68	45	90
5	3	67	5	10
6	1	68	18	35
6	1	67	30	60
6	1	57-0	3	5
6	2	68	35	70
6	2	67	8	15
6	2	57-7	8	15
6	3	68	50	100
7	1	68	25	50
7	1	67	18	35
7	1	57-0	5	10
7	1	57-1	3	5
7	2	67	20	40
7	2	68	30	60
7	3	57-0	10	20
7	3	68	35	70
7	3	67	5	10
8	1	57-1	3	5
8	1	57-7	8	15
8	1	67	20	40
8	1	68	20	40
8	2	68	40	80
8	2	67	8	15
8	2	57-0	3	5
8	3	68	35	70
8	3	67	15	30
9	1	68	45	90
9	1	67	5	10
9	2	68	23	45
9	2	67	8	15
9	2	57-7	8	15
9	2	57-8	5	10
9	2	57-0	8	15
9	3	68	38	75
9	3	67	10	20
9	3	57-8	3	5
10	1	57-8	3	5
10	1	68	43	85

Triangle	Transect	Code	Total Area (m)	Code Area (%)
10	1	67	5	10
10	2	68	28	55
10	2	67	13	25
10	2	57-0	5	10
10	2	57-8	5	10
10	3	68	43	85
10	3	67	5	10
10	3	57-0	3	5
11	1	68	33	65
11	1	67	10	20
11	1	57-8	1	3
11	1	57-7	6	13
11	2	57-7	4	8
11	2	57-8	1	3
11	2	67	8	15
11	2	68	23	45
11	2	67	15	30
11	3	67	20	40
11	3	68	30	60
12	1	67	28	55
12	1	57-0	5	10
12	1	57-9	10	20
12	1	57-7	8	15
12	2	67	15	30
12	2	57-0	23	45
12	2	57-8	3	5
12	2	57-7	10	20
12	3	68	35	70
12	3	67	10	20
12	3	57-0	5	10
13	1	67	15	30
13	1	68	30	60
13	1	57-0	5	10
13	2	68	28	55
13	2	67	10	20
13	2	11	3	5
13	2	57-2	10	20
13	3	68	48	95
13	3	7	3	5
14	1	68	35	70
14	1	67	13	25
14	1	57-0	3	5
14	2	68	40	80
14	2	67	5	10
14	2	57-1	5	10

Triangle	Transect	Code	Total Area (m)	Code Area (%)
14	3	68	30	60
14	3	67	13	25
14	3	57-0	5	10
14	3	57-2	3	5
15	1	68	23	45
15	1	57-7	13	25
15	1	67	15	30
15	2	68	20	40
15	2	57-0	5	10
15	2	57-2	5	10
15	2	57-8	3	5
15	2	67	15	30
15	2	57-7	3	5
15	3	68	45	90
15	3	67	5	10
16	1	68	18	35
16	1	67	30	60
16	1	57-0	3	5
16	2	68	35	70
16	2	67	8	15
16	2	57-7	8	15
16	3	68	50	100
17	1	68	25	50
17	1	67	18	35
17	1	57-0	5	10
17	1	57-1	3	5
17	2	67	20	40
17	2	68	30	60
17	3	57-0	10	20
17	3	68	35	70
17	3	67	5	10
18	1	57-1	3	5
18	1	57-7	8	15
18	1	67	20	40
18	1	68	20	40
18	2	68	40	80
18	2	67	8	15
18	2	57-0	3	5
18	3	68	35	70
18	3	67	15	30
19	1	68	45	90
19	1	67	5	10
19	2	68	23	45
19	2	67	8	15
19	2	57-7	8	15

Triangle	Transect	Code	Total Area (m)	Code Area (%)
19	2	57-8	5	10
19	2	57-0	8	15
19	3	68	38	75
19	3	67	10	20
19	3	57-8	3	5
20	1	57-8	3	5
20	1	68	43	85
20	1	67	5	10
20	2	68	28	55
20	2	67	13	25
20	2	57-0	5	10
20	2	57-8	5	10
20	3	68	43	85
20	3	67	5	10
20	3	57-0	3	5
21	1	68	33	65
21	1	67	10	20
21	1	57-8	1	3
21	1	57-7	6	13
21	2	57-7	4	8
21	2	57-8	1	3
21	2	67	8	15
21	2	68	23	45
21	2	67	15	30
21	3	67	20	40
21	3	68	30	60
22	1	67	28	55
22	1	57-0	5	10
22	1	57-9	10	20
22	1	57-7	8	15
22	2	67	15	30
22	2	57-0	23	45
22	2	57-8	3	5
22	2	57-7	10	20
22	3	68	35	70
22	3	67	10	20
22	3	57-0	5	10
23	1	67	15	30
23	1	68	30	60
23	1	57-0	5	10
23	2	68	28	55
23	2	67	10	20
23	2	11	3	5
23	2	57-2	10	20
23	3	68	48	95

Triangle	Transect	Code	Total Area (m)	Code Area (%)
23	3	7	3	5
24	1	68	35	70
24	1	67	13	25
24	1	57-0	3	5
24	2	68	40	80
24	2	67	5	10
24	2	57-1	5	10
24	3	68	30	60
24	3	67	13	25
24	3	57-0	5	10
24	3	57-2	3	5
25	1	68	23	45
25	1	57-7	13	25
25	1	67	15	30
25	2	68	20	40
25	2	57-0	5	10
25	2	57-2	5	10
25	2	57-8	3	5
25	2	67	15	30
25	2	57-7	3	5
25	3	68	45	90
25	3	67	5	10
26	1	68	18	35
26	1	67	30	60
26	1	57-0	3	5
26	2	68	35	70
26	2	67	8	15
26	2	57-7	8	15
26	3	68	50	100
27	1	68	25	50
27	1	67	18	35
27	1	57-0	5	10
27	1	57-1	3	5
27	2	67	20	40
27	2	68	30	60
27	3	57-0	10	20
27	3	68	35	70
27	3	67	5	10
28	1	57-1	3	5
28	1	57-7	8	15
28	1	67	20	40
28	1	68	20	40
28	2	68	40	80
28	2	67	8	15
28	2	57-0	3	5

Triangle	Transect	Code	Total Area (m)	Code Area (%)
28	3	68	35	70
28	3	67	15	30
29	1	67	28	55
29	1	57-0	5	10
29	1	57-9	10	20
29	1	57-7	8	15
29	2	67	15	30
29	2	57-0	23	45
29	2	57-8	3	5
29	2	57-7	10	20
29	3	68	35	70
29	3	67	10	20
29	3	57-0	5	10
30	1	67	15	30
30	1	68	30	60
30	1	57-0	5	10
30	2	68	28	55
30	2	67	10	20
30	2	11	3	5
30	2	57-2	10	20
30	3	68	48	95
30	3	7	3	5
31	1	68	45	90
31	1	67	5	10
31	2	68	23	45
31	2	67	8	15
31	2	57-7	8	15
31	2	57-8	5	10
31	2	57-0	8	15
31	3	68	38	75
31	3	67	10	20
31	3	57-8	3	5
32	1	57-8	3	5
32	1	68	43	85
32	1	67	5	10
32	2	68	28	55
32	2	67	13	25
32	2	57-0	5	10
32	2	57-8	5	10
32	3	68	43	85
32	3	67	5	10
32	3	57-0	3	5
33	1	68	33	65
33	1	67	10	20
33	1	57-8	1	3

Triangle	Transect	Code	Total Area (m)	Code Area (%)
33	1	57-7	6	13
33	2	57-7	4	8
33	2	57-8	1	3
33	2	67	8	15
33	2	68	23	45
33	2	67	15	30
33	3	67	20	40
33	3	68	30	60
34	1	67	28	55
34	1	57-0	5	10
34	1	57-9	10	20
34	1	57-7	8	15
34	2	67	15	30
34	2	57-0	23	45
34	2	57-8	3	5
34	2	57-7	10	20
34	3	68	35	70
34	3	67	10	20
34	3	57-0	5	10
35	1	67	15	30
35	1	68	30	60
35	1	57-0	5	10
35	2	68	28	55
35	2	67	10	20
35	2	11	3	5
35	2	57-2	10	20
35	3	68	48	95
35	3	7	3	5
36	1	68	35	70
36	1	67	13	25
36	1	57-0	3	5
36	2	68	40	80
36	2	67	5	10
36	2	57-1	5	10
36	3	68	30	60
36	3	67	13	25
36	3	57-0	5	10
36	3	57-2	3	5
37	1	68	23	45
37	1	57-7	13	25
37	1	67	15	30
37	2	68	20	40
37	2	57-0	5	10
37	2	57-2	5	10
37	2	57-8	3	5

Triangle	Transect	Code	Total Area (m)	Code Area (%)
37	2	67	15	30
37	2	57-7	3	5
37	3	68	45	90
37	3	67	5	10
38	1	68	18	35
38	1	67	30	60
38	1	57-0	3	5
38	2	68	35	70
38	2	67	8	15
38	2	57-7	8	15
38	3	68	50	100
39	1	68	25	50
39	1	67	18	35
39	1	57-0	5	10
39	1	57-1	3	5
39	2	67	20	40
39	2	68	30	60
39	3	57-0	10	20
39	3	68	35	70
39	3	67	5	10
40	1	57-1	3	5
40	1	57-7	8	15
40	1	67	20	40
40	1	68	20	40
40	2	68	40	80
40	2	67	8	15
40	2	57-0	3	5
40	3	68	35	70
40	3	67	15	30
41	1	68	45	90
41	1	67	5	10
41	2	68	23	45
41	2	67	8	15
41	2	57-7	8	15
41	2	57-8	5	10
41	2	57-0	8	15
41	3	68	38	75
41	3	67	10	20
41	3	57-8	3	5
42	1	57-8	3	5
42	1	68	43	85
42	1	67	5	10
42	2	68	28	55
42	2	67	13	25
42	2	57-0	5	10

Triangle	Transect	Code	Total Area (m)	Code Area (%)
42	2	57-8	5	10
42	3	68	43	85
42	3	67	5	10
42	3	57-0	3	5
43	1	67	28	55
43	1	57-0	5	10
43	1	57-9	10	20
43	1	57-7	8	15
43	2	67	15	30
43	2	57-0	23	45
43	2	57-8	3	5
43	2	57-7	10	20
43	3	68	35	70
43	3	67	10	20
43	3	57-0	5	10
44	1	67	15	30
44	1	68	30	60
44	1	57-0	5	10
44	2	68	28	55
44	2	67	10	20
44	2	11	3	5
44	2	57-2	10	20
44	3	68	48	95
44	3	7	3	5