FORESTRY

FRDA REPORT 256

THE LONG-TERM SOIL PRODUCTIVITY STUDY IN BRITISH COLUMBIA

ISSN 0835 0752

October 1996

CANADA-BRITISH COLUMBIA PARTNERSHIP AGREEMENT ON FOREST RESOURCE DEVELOPMENT: FRDA II

Canada

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Funding for this publication was provided by the Canada–British Columbia Partnership Agreement on Forest Resource Development: FRDA II—a five year (1991–96) $180 million program cost-shared equally by the federal and provincial governments.

Canadian Cataloguing in Publication Data

Holcmb, R. W.
The long-term soil productivity study in British Columbia

(FRDA report, ISSN 0835-0752 ; 256)

"Written by R.W. Holcomb, Holcomb Communications, based on information provided by the Long-term Soil Productivity Research Team in British Columbia."—Acknowledgements.
"Canada–British Columbia Partnership Agreement on Forest Resource Development: FRDA II."
Co-published by B.C. Ministry of Forests.
Includes bibliographical references: p.
ISBN 0-7726-3063-1

1. Soil productivity – Research – British Columbia. 2. Forest productivity – Research – British Columbia. I. BC Long-term Soil Productivity Research Team. II. Canadian Forest Service. III. Canada–British Columbia Partnership Agreement on Forest Resource Development: FRDA II. IV. British Columbia. Ministry of Forests. V. Title. VI. Series.

SD390.3.C3L66 1996 631.4'22'09711 C96-960350-9

This is a joint publication of the Canadian Forest Service and the British Columbia Ministry of Forests.

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EXECUTIVE SUMMARY

The major portion of this paper is a description of the implementation of British Columbia's Long-term Soil Productivity (LTSP) project (EP 1148). The project is based on a comprehensive model that will provide information about the relative effects of soil compaction and the removal of site organic matter on tree growth. Detailed analysis of climate, soil physical and chemical properties, soil biology, litter decomposition, vegetation cover, and total site productivity will provide information about the mechanisms of the effects. Several decades of research on forest productivity have shown that soil plays a central role in the complex interactions involved in productivity, and within the last decade a group of experiments that focuses on the central role of forest soil has been initiated. These experiments are known as long-term soil productivity (LTSP) studies. The experiments are designed to obtain information that can be used in making management decisions covering a wide range of harvesting techniques and biogeoclimatic zones. There are now about forty sites in the United States and Canada, and related studies are under way or being considered for Australia, Chile, and New Zealand. The international nature of the research will enable British Columbia scientists to compare results with those from research sites in other countries and other ecosystems. However, the full significance of this project cannot be appreciated without first reviewing basic principles of forest ecology and methods of forest ecosystem research.

ACKNOWLEDGEMENTS

This report was written by R.W Holcomb, Holcomb Communications, based on information provided by the Long-term Soil Productivity Research Team in British Columbia. Funding for this research has been provided by the Forest Resource Development Agreement (FRDA) II, and by Forest Renewal B.C. (FRBC).

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1 PRODUCTION AND ECOLOGY

1.1 Production

Traditionally, forest managers have focused on volume of marketable timber and its use in assessing forest sites for production. Since long-term productivity involves re-planting and harvesting sites more than once, however, site assessment based only on timber volume is inadequate. Foresters appreciate that to sustain production, they must understand the factors that control it.

One of the most basic of these factors is photosynthesis (the conversion, by plants, of light energy and CO_2 to chemical energy or sugars). As a tree allocates photosynthate, production of roots, foliage, and reproductive structures (such as cones) all take precedence over wood production. Thus, in long-term productivity studies, the concept of net primary productivity (NPP) is a better measure of what occurs in the forest than volume of marketable timber alone. NPP is defined as the gross primary productivity (total plant weight or biomass) resulting from photosynthesis, minus the respiration of all plant parts.

However, looking at the total growth and total respiration of all the parts of all the plants in a forest is, in fact, looking at the forest ecosystem

1.2 Forest Ecosystems

Forest ecosystems are distinguished by progressive development and complex interactions.

Progressive development involves succession—the development of a biological community and the progression of one community after another. Changes in community development are most rapid in early succession (a matter of months or years) and least rapid as succession approaches maturity (in the order of centuries). Secondary succession begins with natural disturbance such as wildfire, flood, windstorms, insects, pathogens, or human-caused disturbance such as mechanical or chemical clearing, prescribed fires, or tree harvesting.

The special subset of secondary succession events associated with logging are

- Organic matter is removed. At the very least, tree trunks (boles) of marketable timber are removed. Slash (organic matter other than boles) is often moved or burned to make planting easier and to improve early growth.
- Selected seedlings are planted in the harvested areas to 'jump start' the succession in favour of marketable tree species.
- Commercial operations result in soil disturbance in the form of soil compaction and soil relocation for roads and landings.

The complex interactions of plants, animals, and micro-organisms in forest ecosystems involve everything in the forest being affected by and affecting everything else. Solar radiation (light and heat), atmospheric gases, the soil, living organisms, and dead organisms are constantly interacting and changing. The type of soil influences which plants first become established; these plants influence the way soil develops, which, in turn, influences the next succession of plants—and so on. Once a succession has started in a certain direction it will proceed according to its own rules (which are not completely understood), and may or may not move in a direction suitable for timber production.

In summary, forest ecosystem research involves tens of thousands of interactions taking place over hundreds of years and operating by rules we are just beginning to understand. This may sound discouraging, but ecologists have devised strategies for dealing with this difficult situation. Following are a few examples of work that has been done.

1.3 Forest Ecology Studies

1.3.1 Types of studies

There are two types of studies that can provide information about long-term forest ecology in a relatively short time frame—chronosequence studies and retrospective studies.

Chronosequence studies substitute space for time by selecting situations that are similar in all respects except for location. One example of this type of study is the Coastal Forest Chronosequences project, established on Vancouver Island by the Canadian Forest Service to evaluate the effects of converting old-growth forests to managed forests. In this project, four stand ages (old-growth, mature, immature, and regeneration) with similar slope, elevation, and aspect have been selected. By simultaneously studying these sites, researchers can obtain results that provide information about the 200-year development of old-growth forests in the Coastal Western Hemlock zone of southern Vancouver Island.

Retrospective studies infer past conditions from evidence of plant parts that existed in the past and that can be studied in the present, especially annual ring patterns and pollen records. Annual ring patterns are useful because trees live a long time; some living trees can provide information about events 2000 years ago. Pollen records are useful because pollen is very resistant to decay. Recently published results of pollen studies provide fairly detailed information about the appearance and distribution of many British Columbia tree species since glaciation.

Retrospective and chronosequence studies have provided much valuable information about forest ecosystems, but they have major limitations.

1. They cannot provide information about alternative situations.
2. Retrospective studies cannot provide details of subtle chemical, physical, and biological processes.
3. The assumption of similarity of factors such as forest type or impact type is not guaranteed.
4. They may not involve a particular treatment or condition of interest.

To overcome these limitations long-term studies must be established.

In northern Europe, long-term studies date back to near the beginning of this century. Originally, they tended to have limited scope (such as fertilization trials), but the records of early observations have provided the basis for later studies.

There are several long-term studies in the United States. The oldest is the Pack Forest in the upper Hudson River Valley of New York State, which was acquired in 1927. The best known is the 3200-ha Hubbard Brook Experimental Forest in the White Mountains of New Hampshire, which was established in 1955.

The oldest research station in British Columbia was established in 1924 at Aleza Lake, east of Prince George. The Cowichan Lake Research Station on Vancouver Island began in the late 1920s, and the University of British Columbia Malcolm Knapp Research Forest, near Haney, has conducted long-term research dating back to the 1950s. Much of the B.C. Ministry of Forests' research originates at the regional level, and a number of studies have baseline data that date back 30 years or more. Like the early European studies, many of these are focused on a relatively narrow range of factors associated directly with tree growth.

1.3.2 Need for additional studies

Long-term studies, coupled with good extension and demonstration capabilities, provide the mechanism for communicating new recommendations for forest management to those who most need the information, from District staff to company foresters and the public. Several studies have recently been undertaken to meet the need for better information about forest ecology. Those designed specifically to investigate the effects on forest ecosystems of soil compaction and organic matter removal are referred to as long-term soil productivity (LTSP) studies.

2 LONG-TERM SOIL PRODUCTIVITY STUDIES

2.1 History

During the past few decades in British Columbia, much forest research has been initiated at the regional level to find answers to local harvesting and reforestation issues. By the 1980s, many researchers began to realize that the long-term productivity of forests could not be measured by assessing the short-term effects of constantly changing harvesting and reforestation techniques. It became evident that research scientists needed to measure the driving factors in forest productivity that are common to all technologies. In this way, results from process-oriented research could be applied to new technologies, and to the development of regulations, standards, and assessment or monitoring procedures.

During the same period, the United States Congress passed an act that "binds the Forest Service to achieve and sustain outputs of various renewable resources without permanently impairing the productivity of the land." The act was later expanded to require "research and monitoring...to protect the permanent productivity of the land." In response to this legislation, soil scientists and U.S. government officials drafted an outline of long-term study issues. After extensive technical review in the U.S. and abroad, details for long-term soil productivity (LTSP) studies were approved in 1989. These details serve as a template for regional studies in the U.S. and other countries.

In the U.S., there are now about 40 LTSP sites located in various states. There are studies in New Zealand and Ontario with many of the LTSP criteria, and efforts are under way to establish sites in Australia and Chile. The British Columbia project, outlined below, is the only fully replicated LTSP study in Canada.

Bob Powers of the USDA Forest Service's Pacific Southwest Research Station in Redding, California helped pioneer the LTSP model, and currently coordinates the U.S. studies. In the summer of 1988 Powers presented ideas about long-term soil productivity studies at the Seventh North American Forest Soils Conference, held at the University of British Columbia campus in Vancouver. Anne Macadam, who was the Assistant Pedologist in the Prince Rupert Forest Region at the time, and Graeme Hope, a private contractor at the time, attended the conference.

The suitability of this approach for British Columbia's forest researchers was immediately apparent, and Anne Macadam contacted Powers for more details. She then talked about the project with other regional soil scientists and with members of the Research Branch in Victoria. In the spring and early summer of

1990, meetings were held in which financial and tactical details of the project were firmed up.

During this time, a second group was working to establish an LTSP study in British Columbia. A New Zealand researcher who was familiar with Powers' work, and several UBC Faculty of Forestry researchers, made contacts with provincial and federal forestry personnel and with forest industry representatives to further this effort.

Eventually, the B.C. Ministry of Forests regional soil scientists started the study. Graeme Hope was hired to write a working plan for LTSP research in the Prince George, Prince Rupert, and Cariboo forest regions. The other authors of this plan, Anne Macadam, Marty Osberg, Rick Trowbridge, and Marty Kranabetter, were the original core group of the British Columbia project. Funding was obtained from FRDA II (Forest Resource Development Agreement), and site selection began in the Prince George and Prince Rupert regions during the 1991 field season, and in 1992 in the Cariboo.

The provincial project is managed by an LTSP study research team consisting of the principal researchers. This group meets once a year to evaluate progress and to modify or expand post-establishment stages of the project. The group also participates in the international LTSP Technical Committee meeting.

FRDA II funding ended in 1995. Since B.C. Ministry of Forests budgets are proposed on a yearly basis, no projects are funded for more than 1 year at a time. This project was initiated on the assumption that funding for the minimum maintenance and baseline observations at the sites could be written into the regional operational budgets on a yearly basis. Funding for more-detailed measurements and for the ancillary studies must be obtained elsewhere. In 1996, funding to continue the research at the current installations and to expand research in the Boreal White and Black Spruce (BWBS) and Interior Douglas-fir (IDF) zones was obtained through Forest Renewal B.C.

2.2 The Scientific Basis for LTSP Studies

2.2.1 Simplifying Assumptions

When studying something as complex as a forest, it is necessary to focus on a few factors that can be controlled and measured. In the present case, the first step was to concentrate on soil productivity. The next step was to focus on the aspects of forest development that are most affected by logging practices, and that can be controlled.

All logging practices disturb soil and remove organic matter. Research has been conducted on these two site factors for decades, and it is safe to say that, within limits, compaction reduces productivity, while retention of organic matter increases it. The issue is to find out what these limits are. Thus, the second step toward simplification is to focus on these two variables—soil porosity (compaction) and organic matter. A conceptual model that focuses on soil productivity and uses compaction and organic matter removal as the controllable variables is shown in Figure 1.

A simple understanding of plant growth involves only the top and bottom portions of Figure 1. Plants are anchored in the ground, they absorb sunlight, water, and gases, and they grow. What we see is the growth above ground. The soil is thought of primarily as an anchoring device, although there are vague notions that soil plays a role in collecting and releasing water and that it holds nutrients (fertilizer) that help plants grow.

A more detailed analysis of Figure 1 shows a large number of activities taking place within the soil. In the diagram these activities are clustered under two headings: soil porosity on the left and site organic matter on the right. Working with this model enables one to set up forest soils research projects with soil porosity and site organic matter as the two major variables.

Soil porosity is an expression of the number and size of the pores in the soil. The opposite of a porous soil is a compacted soil. In Figure 1, it can be seen that soil porosity plays an important role in gas and water exchange, erosion, and root development.

Much of the site organic matter is at the soil surface in what is called the organic horizon. It is formed from remains of living things, ranging from one-celled organisms to huge trees. In Figure 1, it can be seen that organic matter plays an important role in gas and water exchange, in erosion, and as energy and nutrient reservoirs.

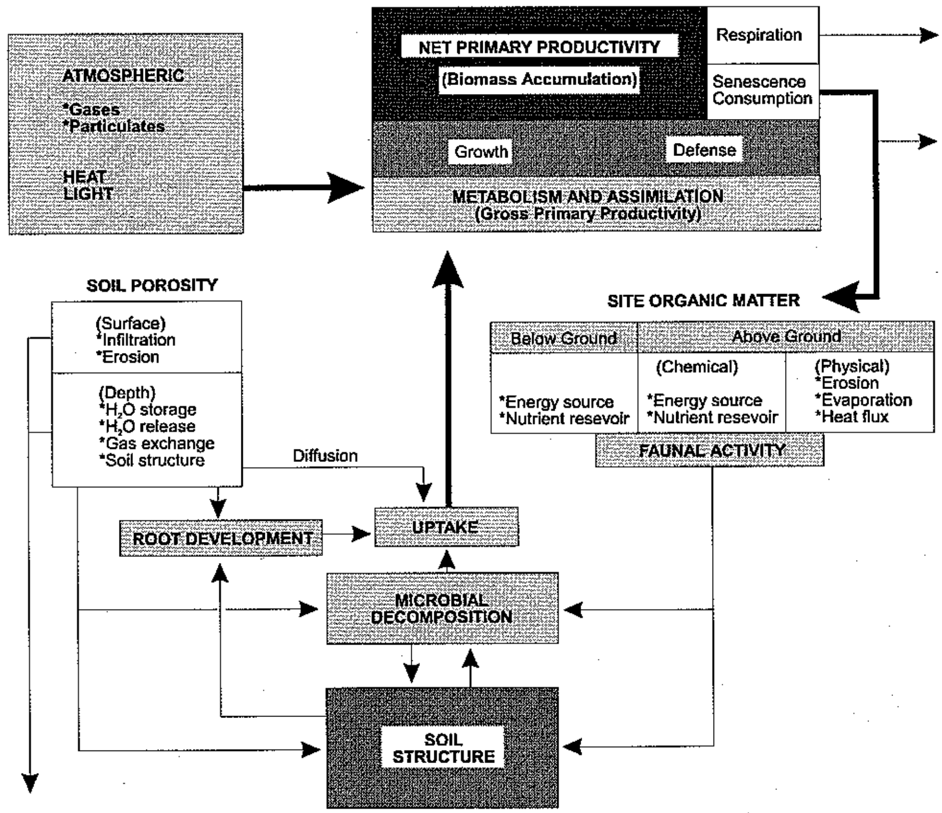


FIGURE 1. Conceptual model of the roles of soil porosity and site organic matter in regulating the processes controlling site productivity (from Powers 1990).

Nothing is permanent in the forest, and materials are constantly being cycled, as shown by the arrows in Figure 1. Of all the materials that are cycled in forests, the most widely studied are carbon and nitrogen. Both nitrogen and carbon can be found in every part of the system—in the atmosphere above and below ground, in living and dead plant and animal material, and in mineral compounds. A large amount of carbon in an old-growth forest is in the trees. Much of the nitrogen is distributed between living plants and the organic horizon, and, in the cool boreal forest of British Columbia, the nitrogen content of the forest floor often exceeds that in the living vegetation.

2.2.2 Site specificity

Soil porosity and site organic matter have been studied for decades. One might then ask, "why another study?"

This study is necessary because of site specificity. Practices that could be quite destructive in one forest ecosystem may have little effect in another. For example, reduction of site organic matter generally reduces production. But on sites that accumulate vast amounts of slowly decaying, acidic, organic matter, reduction of site organic matter might give short-term increases in tree growth. Compaction generally reduces production. But light compaction has been shown to increase short-term tree growth on some dry sites with loose, sandy soil.

Because of this site variability, two things must be done to ensure general applicability of results.

First, the variables (in this case soil porosity and site organic matter) must be established so that the extremes are well outside the range of effects produced by normal logging operations. The object is not to exactly duplicate effects of logging practices, but to establish an experiment that will produce meaningful results that can be used in making management decisions across a broad range of harvest conditions.

Second, a range of sites with some overlapping characteristics must be established. Because of the cost and time involved, it would not be feasible to set up experiments in all biogeoclimatic zones. But since the British Columbia experiment is part of an international collaborative effort, the results can be more widely extrapolated than results from isolated experiments.

3 THE BRITISH COLUMBIA PROJECT

3.1 Summary

The basic idea of these experiments is to determine the long-term effects of soil compaction and removal of organic matter on forest production and the factors that contribute to forest production. This is done by performing the following:

- making detailed observations on a site;
- harvesting the site;
- treating the site with different levels of organic matter removal and soil compaction;
- replanting the site;
- following the progress of the tree growth;
- monitoring silvicultural practices such as weeding and thinning; and
- observing a wide range of environmental factors.

The following narrative is a brief elaboration of these seven points. Additional details can be found in the appendices of this paper and in the original working plan (Hope *et al.* 1990).

3.2 Objectives

The broad objectives of the study are to investigate and demonstrate how soil compaction and organic matter removal (soil modification) affect forest productivity over the long term, and to gain an understanding of how the fundamental processes controlling productivity are affected by this soil modification.

The specific objectives are as follows.

1) Determine the effects of different levels of organic matter removal (above-ground biomass and forest floor) and soil compaction on the long-term productivity of forest soils for a range of forest ecosystems.

2) Study the long-term effects of organic matter removal and soil compaction on soil nutrient status, soil physical properties, soil microclimate, soil biological activity, and nutrient cycling.

3) Identify causal relationships between long-term forest productivity and soil properties altered by soil compaction and organic-matter removal.

4) Investigate the influence of ecosystem type on the effects of soil modification on long-term soil productivity.

5) Provide long-term research sites for detailed studies into forest soils, nutrient cycling, and forest productivity.

6) Provide sites that illustrate the effects of soil disturbance on forest productivity for extension and demonstration purposes.

3.3 Methods

3.3.1 Basic design

The design of this experiment is based on the simplifying assumption that soil productivity is strongly influenced by modifications to two variables, soil porosity and organic matter. There are three levels of each variable resulting in a basic 3 x 3 (compaction x organic matter) factorial design. In addition to these nine treatment plots at each site, there is an unharvested reference plot, bringing the total to ten (Figure 2). The responses of two tree species will be studied at each site, so there are split plots within the factorial design.

3.3.2 Study sites

In the original working plan, three primary study sites were proposed for three different subzones in the Sub-boreal Spruce (SBS) zone. The following sites were established:

- **Log Lake Site**. In the Prince George District of the Prince George Region, Marty Kranabetter established a site near Log Lake. The site is now managed by Paul Sanborn.

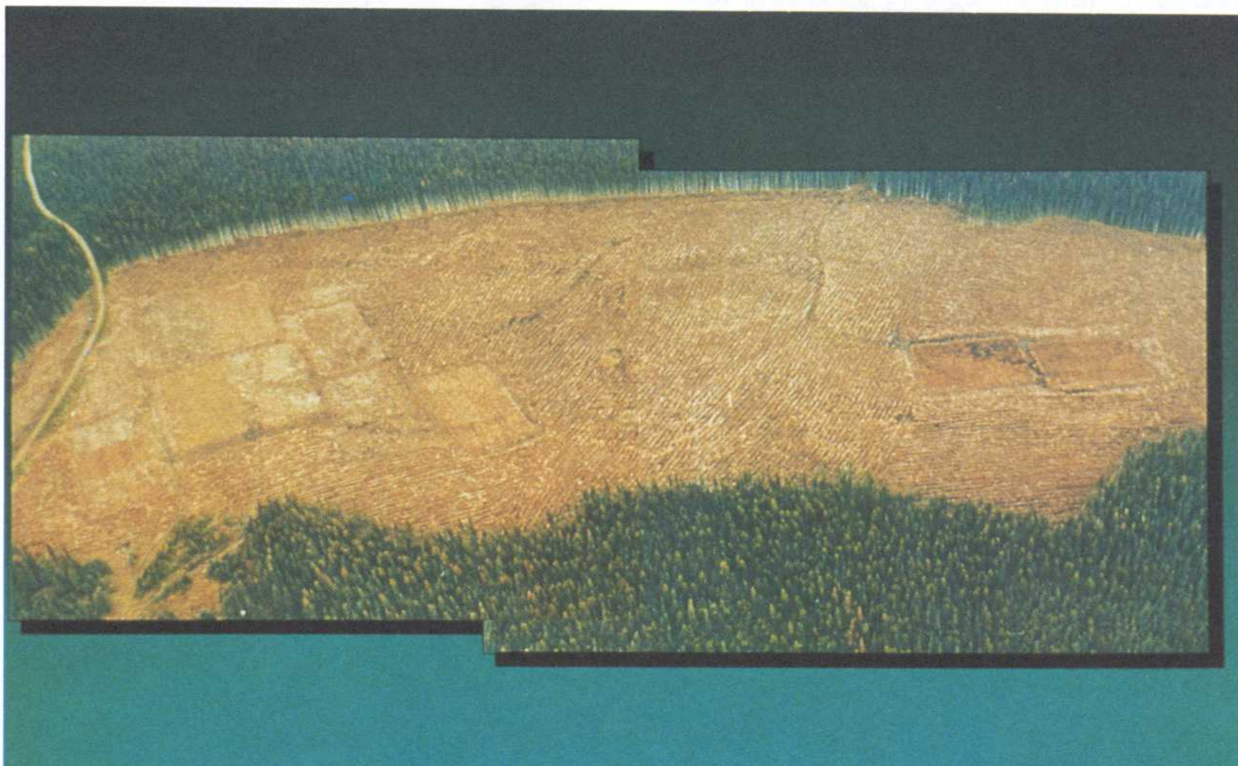


FIGURE 2. Aerial view of Topley installation showing the nine treatment plots and one demonstration plot.

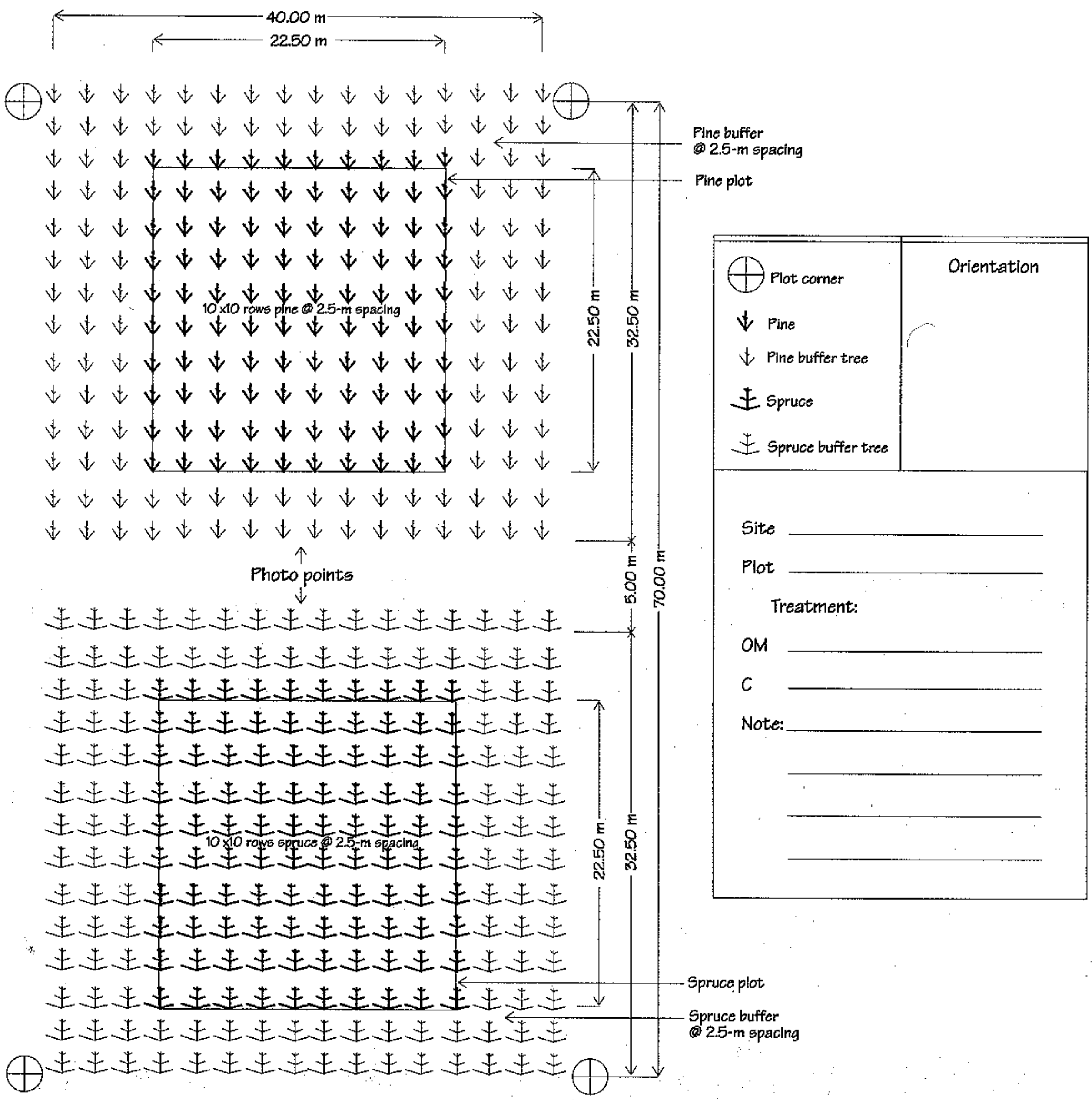


FIGURE 3. Treatment plot and subplot layouts.

- **Topley Site.** In the Morice District of the Prince Rupert Region, Rick Trowbridge established a site near Topley. The site is now managed by Marty Kranabetter.

- **Skulow Lake Site.** In the Williams Lake District of the Cariboo Region, Bill Chapman established and manages a site near Skulow Lake.

After the original working plan had been written, a fourth site was added in the BWBS zone.

- **Kiskatinaw River Site.** In the Dawson Creek Forest District of the Prince George Region, Richard Kabzems established and manages a site along the Kiskatinaw River.

Forest Renewal B.C. has recently funded extension of the LTSP into two additional sites in the BWBS, and into three sites in the IDF.

Site characteristics, plot layout, and driving instructions to the established sites can be found in Appendix 1. Names and addresses of all principal researchers are in Appendix 2.

3.3.3 Plot layout

Sites were selected both for demonstration and extension purposes and to obtain the broadest range of conditions within the zone. Plots represent typical conditions for the subzones in which they are located, and have uniform soil and site features. Arrangements have been made with District and/or company staff for administration of the plots for at least one timber rotation (80–120 years).

About 4 ha of land is required for the experimental plots, which are rectangles surrounded by buffer strips. A standard split plot is shown in Figure 3.

There is no experimental necessity that the plots be contiguous. An unlogged reference plot of at least 1 ha with similar site and soil characteristics is retained close to the treatment plots (Figure 4). Additional plots have been added at some of the sites, and some experiments are designed so that the buffer strips around the plots can be used. Extra trees planted in the buffer will be used for destructive sampling.

FIGURE 4. Uncut reference forest at the Topley installation.

Organic Matter Retention

OM_1C_0	OM_1C_1	OM_1C_2
OM_2C_0	OM_2C_1	OM_2C_2
OM_3C_0	OM_3C_1	OM_3C_2

FIGURE 5. Generalized layout of the 3 x 3 factorial design for organic-matter removal and soil compaction treatments.

FIGURE 6. Bucket on backhoe was used to peel off the forest floor.

FIGURE 7. Tamping plate on backhoe was used to compact the mineral soil.

3.3.4 Pre-harvest measures

Prior to timber harvest, the following observations were made:

- ecosystem descriptions;
- soil chemical properties;
- soil physical properties;
- forest floor mass;
- native vegetation; and
- timber volume and productivity.

3.3.5 Harvesting

Sites were harvested during the winter on a snowpack of at least 50 cm. Harvesting techniques were closely monitored to enable researchers to control the resultant conditions as much as practicable. Techniques included hand-felling trees toward the plot edges, restricting skidder traffic to the alleys, and cutting stumps as close to the ground as possible.

3.3.6 Treatments

The following treatment codes were used:

OM_1 = boles (tree trunks) only removed
OM_2 = boles + crowns removed
OM_3 = boles, crowns, + forest floor removed
C_0 = no compaction
C_1 = intermediate compaction
C_2 = heavy compaction

Organic matter was removed in midsummer when the sites were dry (Figure 6). Manual labour was used when necessary to avoid compaction.

On the OM_1 plots, downed woody material was removed before the compaction operation, and then redistributed after compaction.

Intermediate and heavy compaction are defined as 40 and 80%, respectively, of the difference between a hypothetical growth-limiting maximum and pre-harvest conditions.

It is measured as depth of imprint. The equipment and techniques required to achieve proper compaction were determined by trial and error on separate plots (Figure 7).

3.3.7 Post-treatment sampling

After the treatments are completed, the following observations are made:

Atmospheric and soil climate. A weather station has been located at each site to record air temperature and precipitation. An ancillary study on soil atmosphere has been initiated, and baseline data are being collected at all four established sites.

Slash loading. Standardized measurements have been made of slash, needle litter, and decaying wood.

Soils. Chemical and physical soil properties have been measured at year 1, and will be measured at years 5, 15, 25, 50, and before second harvest.

Soil biology. An experiment to measure decomposition through the weight loss of a standard material placed within the rooting zone has been initiated and will continue. An ancillary study has been established to measure root development, seedling nutrition, and ectomycorrhizal fungi. In another ancillary study, observations are being made on abundance and diversity of soil fauna.

Native vegetation. Percent cover of ten dominant species present in mid-summer at year 1 has been determined for most sites. Observations will be made again at years 5, 15, 25, 50, and before second harvest.

3.3.8 Conifer regeneration

Planting has been done with standard stock types. Planting spots were hand-screefed when necessary, but there was no other site preparation. Reforestation on the Log Lake, Topley, and Skulow Lake sites was with containerized seedlings of lodgepole pine (*Pinus contorta*) and hybrid spruce (*Picea engelmannii* x *glauca*). At the Kiskatinaw Lake site, reforestation involved planting white spruce (*Picea glauca*) seedlings and allowing aspen (*Populus tremuloides*) to regenerate from root suckers.

Seedling survival and condition is being monitored, and dead seedlings are being replaced. The minimum amount of brush control required for survival is being practiced.

Seedling biomass, height, and nutrient content will be measured and analyzed.

Scheduling

The treatments listed above are being carried out according to the following schedule:

Year -1: Site selection, plot location, pre-harvest sampling

Year 0: Timber harvesting, post-harvest sampling, treatment application (compaction and organic material removal)

Year 1: Planting of seedlings, soil nutrient and physical sampling, vegetation removal, vegetation assessment, crop tree biomass, end-of-season tree measurements

Year 2: Vegetation control, vegetation assessment

Year 3: Vegetation control, crop tree biomass, end-of-season tree measurements

Year 4: Vegetation control

Year 5: Soil sampling. Net primary production (NPP) measurements including: crop and noncrop vegetation biomass and nutrients, vegetation assessment, end-of-season tree measurements

Years 10, 15, 25, 50, and second pre-harvest: As for year 5

The best account of the actual schedule for each installation is the Chronology in Appendix 4, which lists work as it was actually completed.

3.4 Ancillary Studies

The three sites in the SBS zone comprise the largest replicated study of the effect of soil modification in this zone. The growth of aspen in the BWBS site can be compared to aspen on other LTSP sites in the U.S. All sites are set up to collect a large number of baseline data. It is possible, therefore, to fit other studies into this established structure.

Presently there are three ancillary studies that use the four installations of this project. Following is a brief summary of the experiments being conducted in these studies. More detail can be found in the working plans cited in the Bibliography.

3.4.1 Ectomycorrhizal fungi, root development, and seedling nutrition

Ectomycorrhizal fungi develop intimately within the feeder roots of host plants. This enables them to enhance access to soil nutrients (including nitrogen) and water for their plant hosts, and to obtain carbon and energy in return. This association of ectomycorrhizal fungi with roots and the resultant nutritional exchanges place this research in the centre of studies relating soils and plant growth.

Shannon Berch, a research scientist at the Glyn Road Research Station in Victoria, British Columbia has established projects at all four LTSP sites to study ectomycorrhizal fungi. The basic objectives of this work are to determine the effects of clearcutting, soil compaction, and organic matter removal on the following:

- the diversity and abundance of ectomycorrhizal fungi,
- seedling root and shoot development and structure, and
- seedling nutrition.

Subsamples of seedlings from the nurseries are collected and examined for mycorrhizal colonization before outplanting.

Since seedling examination is destructive, extra seedlings are planted in the buffer zones, which have undergone the same treatments as the experimental plots. Seedlings are examined for mycorrhizal colonization and fine root structure about 2 years after planting and again over time. In addition root biomass, seedling growth, and nutrient content will be determined on the outplanted seedlings. The abundance and variety of ectomycorrhizal fungi in the unlogged area will be compared with logged areas.

3.4.2 Soil fauna

Soil fauna play a major role in the nitrogen cycling process by grazing on microbes and detritus, stimulating bacterial and fungal activity, and aiding in forest litter decomposition, which releases important plant nutrients. Soil fauna can also be indicators of soil quality.

Since no previous work has examined the soil fauna community in the SBS or BWBS zones in British Columbia, the LTSP study presents an obvious starting point for such work. Jeff Battigelli, who is currently a graduate student at the University of Alberta in Edmonton, is conducting this experiment.

This study will provide baseline information for future work on soil fauna, and will establish a better understanding of the abundance and diversity of soil fauna and how they are affected by these treatments. The soil fauna study has three objectives:

- explore the effect of treatments on the soil fauna community;
- determine which soil fauna are associated with seedlings before outplanting; and
- examine the relationship of soil fauna to decomposition rates on treatment plots.

Sampling is done three times a year using three extraction methods. Furthermore, seedlings from the nurseries and those collected after planting (as outlined in the ectomycorrhizal fungi study) will also be sampled for soil fauna.

3.4.3 Soil atmosphere

On the left-hand side of the conceptual model shown in Figure 1 there is reference to 'gas exchange' taking place within the soil. The gases involved make up the soil atmosphere and include, among others, water vapour, oxygen, carbon dioxide, and ethylene (the last being a plant growth regulator). Unlike the above-ground atmosphere, where the constituent gases remain relatively constant, there can be a great deal of variation in soil atmosphere gases. There is a strong correlation between soil porosity and the exchange of gases between the soil and the earth's atmosphere.

Laboratory work indicates that soil gases could be a more important constraint on conifer root growth in compacted soil than soil strength. However, there are very few 'real world' data collected from field sites that allow for corroboration of these lab results. The LTSP studies provide such a 'real world'.

Robert van den Driessche and Timothy Conlin of the Glyn Road Research Station in Victoria have set up soil atmosphere monitoring stations on the four LTSP sites. Soil atmosphere samples collected from the sites are analyzed using equipment available at the Glyn Road Laboratory. The results of the analysis will be used to design experiments on root-growth responses to soil atmosphere, and the results of the experiments will be used to model tree seedling response to soil compaction.

3.5 Other Studies

The fifth experimental objective is to "provide long-term research sites for detailed studies into forest soils, nutrient cycling, and forest productivity." There are several additional research projects being considered at the present time, and four are in progress.

Cindy Prescott of the Forest Science Department at the University of British Columbia is conducting decomposition studies as part of a province-wide project to develop models that will predict decomposition rates of different types of litter in different biogeoclimatic zones, and with different management schemes.

The Canadian Intersite Decomposition Experiment (CIDET) is a national program with similar objectives. Tony Trofymow of the Pacific Forestry Centre in Victoria is the study leader for this project and supervises a study at the Topley site that is part of this work.

Paige Axelrood of the British Columbia Research Institute (BCRI) and Julian Davies of the Department of Microbiology and Immunology, UBC are characterizing the microbial diversity of the soils and paying particular attention to the bacteria involved in decomposition and root colonization.

Andrei Startsev of the Alberta Environmental Centre is measuring the effects of the treatments on surface infiltrability and saturated hydraulic conductivity of the soil. These measurements will be repeated over time to examine the effects of natural processes, such as the influence of vegetation, on the structure of the surface soil

3.6 Communication of Results

During field trips to the installations, the regional soil scientists are able to demonstrate results clearly to field staff and the public.

Results of the LTSP research will be used to refine management recommendations for allowable amounts of soil disturbance provided in the Forest Practices Code Soil Conservation Guidebook, and will be written up as a variety of reports and scientific journal articles. Recently, a data storage protocol has been developed for all sites, and a detailed establishment report has been written.

3.7 Conclusions

The most basic findings of the LTSP study will be the effects of three soil compaction and three organic-matter removal treatments on the overall site productivity. It will be possible to determine how much these factors affect growth. Then, by analyzing the detailed physical, chemical, and biological information associated with the treatment effects, it should be possible to determine at least some of the reasons behind the changes. This information can, in turn, be used to make management decisions that minimize productivity losses. Stated in more general terms, LTSP studies will help foresters and soil scientists better understand how forest systems function, and, therefore, help them to refine aspects of the Forest Practices Code Soil Conservation Guidebook that deal with allowable levels of soil disturbance.

Since the details of the baseline observations and the length of the study are unprecedented in northern coniferous forests in British Columbia, clarification of the cause-and-effect relationships between soil modification and long-term productivity will provide a new understanding of how these forests function.

APPENDIX 1. Experimental sites

Location of long-term soil productivity (EP 1148) sites in British Columbia.

Log Lake Installation

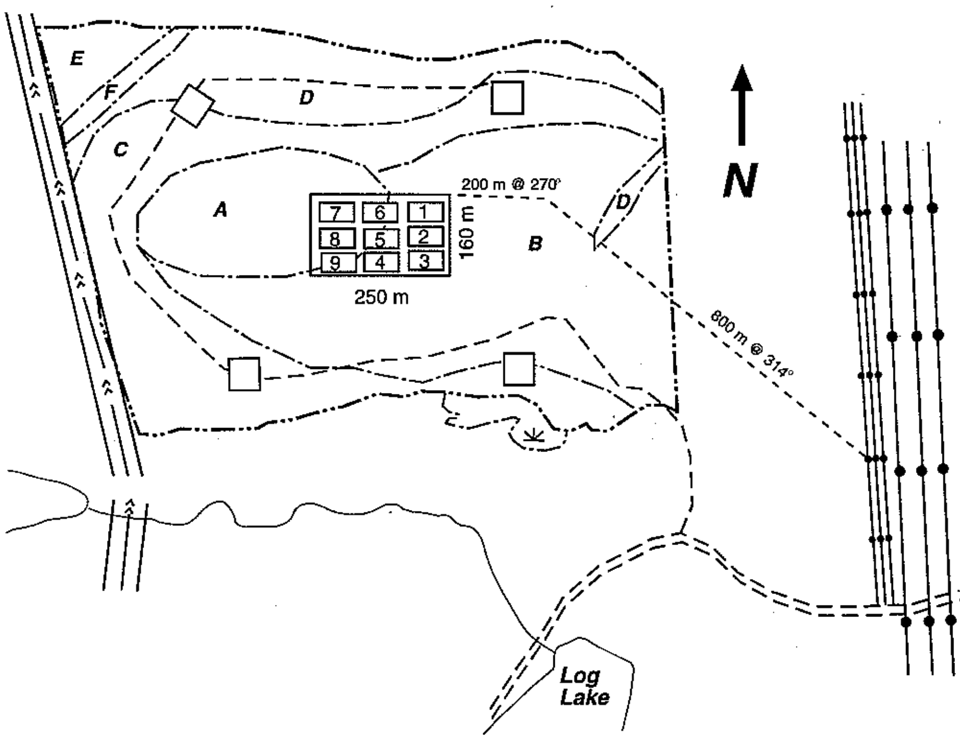
Jurisdiction: Prince George Region, Prince George Forest District

Contact Person: Paul Sanborn, Soil Scientist, Prince George Forest Region

Harvest Year: 1992

Site Location:

Map sheet: 93J.038



Driving instructions from nearest town: From Highway 97 approximately 60 km north of Prince George, take the Chichinka–Log Lake forest road and travel about 3.5 km to the site.

Elevation: 780–790 metres *Latitude*: 54° 21' *Longitude*: 122° 37'

Site Description:

Slope and aspect: On the crest of an ENE–WSW tending drumlin.

Biogeoclimatic type: Warm, cool subzone of the Sub-Boreal Spruce Zone (SBSwk1)

Vegetation: Douglas-fir and spruce, with lesser amounts of lodgepole pine and subalpine fir.

Dominant Soil type: Orthic Humo-Ferric Podzol

Topley Installation

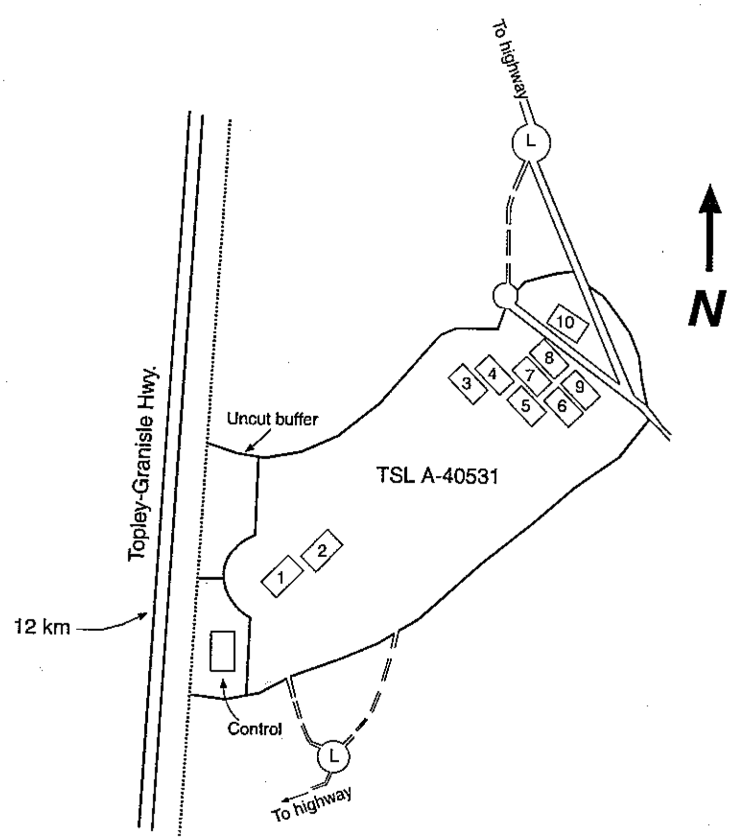
Jurisdiction: Prince Rupert Region, Morice Forest District

Contact Person: Marty Kranabetter, Soil Scientist, Prince Rupert Forest Region

Harvest Year: 1993

Site Location:

Map sheet: 93L/9



Driving instructions from nearest town: Twelve km north of Topley on the east side of the Granisle highway

Elevation: Approx. 1100 metres *Latitude*: 54° 37' *Longitude*: 126° 18'

Site Description:

Slope and aspect: Gently to moderately (2–12%) sloping on a westerly aspect

Biogeoclimatic type: Moist, cold subzone of the Sub-boreal Spruce Zone (SBSmc)

Vegetation: Dominated by subalpine fir, lodgepole pine, and hybrid spruce, with small amounts of aspen and cottonwood

Dominant Soil type: Orthic Gray Luvisol

Skulow Lake Installation

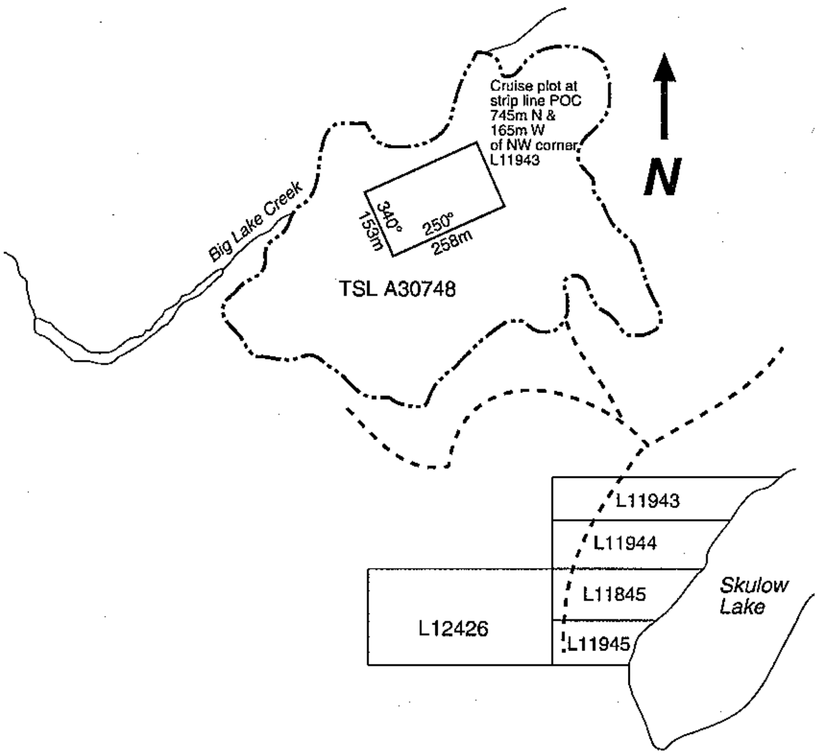
Jurisdiction: Cariboo Region, Williams Lake Forest District

Contact Person: Bill Chapman, Soil Scientist, Cariboo Forest Region

Harvest Year: 1994

Site Location:

Map sheet: 93A.006 and 93.011



Driving instructions from nearest town: From Williams Lake drive east on Highway 97 to 150 Mile House, turn left (north) on the Likely-Horsefly highway, drive about 5 km and take a left to Likely, drive for about 25 km to Skulow Lake, just opposite Skulow Lake take a small road going off NE, drive along that road about 1 km to the site.

Elevation: 1050 metres ***Latitude***: 52° 20' ***Longitude***: 121° 55'

Site Description:

Slope and aspect: 0%, NA

Biogeoclimatic type: dry, warm subzone of the Sub-boreal Spruce Zone (SBSdw)

Vegetation: Dominated by lodgepole pine, with minor amounts of hybrid spruce, Douglas-fir, aspen, and cottonwood.

Dominant Soil type: Orthic Gray Luvisol

Kiskatinaw River Installation

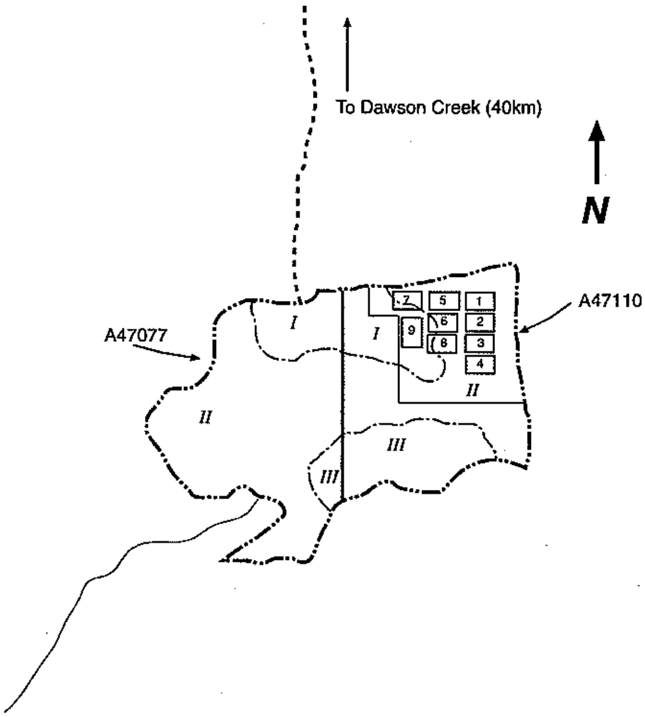
Jurisdiction: Prince George Region, Dawson Creek Forest District

Contact Person: Richard Kabzems, Research Ecologist, Fort. St. John Forest District

Harvest Year: 1995

Site Location:

Map sheet: 93P



Driving instructions from nearest town:

From Dawson Creek, go 34 km north on Highway 97, turn right (east) on Old Alaska Highway (Road 64). Proceed for 2 km, then turn left at Road 24 (near Mile 22 highways yard). Follow main gravel road approx. 5 km to four-way intersection, turn right (east) for 800 m, then turn left (last farmstead is on your left), go east for 1.4 km and turn right (south) at four-way intersection and go 600 m to roadblock, walk 800 m along old logging road to reach site. From Fort St. John go south approx. 35 km along Highway 97, turn left on Old Alaska Highway and follow above directions.

Altitude: 720 metres   *Latitude*: 55°58'   *Longitude*: 120°28'

Site Description:

Slope and aspect: 4%, south aspect

Biogeoclimatic type: Moist, warm subzone of Boreal White and Black Spruce Zone (BWBSmw)

Vegetation: Dominated by aspen, with small amounts of white spruce and cottonwood.

Dominant Soil type: Gleyed Grey Luvisol

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APPENDIX 3. LTSP Bibliography

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APPENDIX 4. LTSP Chronology

Season	Year	Log Lake	Topley	Skulow Lake	Kiskatinaw River
Field season	1991	- plot selection - site description - pre-harvest sampling	- plot selection - site description - start of pre-harvest sampling		
Winter	1991/92	- timber harvesting			
Field season	1992	- organic matter removal - start of compaction of soil	- pre-harvest sampling completed	- plot selection	
Winter	1992/93		- timber harvesting		
Field season	1993	- compaction of soil completed	- organic matter removal - compaction of soil	- site description - pre-harvest-sampling	
Winter	1993/94			- timber harvesting	
Field season	1994	- planting of seedlings - post-treatment assessment	- planting of seedlings - post-treatment assessment	- organic matter removal - compaction of soil	- plot selection - site description - pre-harvest assessment
Winter	1994/95				- timber harvesting
Field season	1995	- monitoring - stand tending	- monitoring - stand tending	- planting of seedlings - post-treatment assessment	- organic matter removal - compaction of soil - planting of seedlings - evaluation of aspen shoots