

A SURVEY OF  
DISTURBED LANDS  
WITHIN  
PRINCE ALBERT MODEL FOREST  
TO ASSESS PRODUCTIVITY

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A Report Submitted to:  
THE PRINCE ALBERT MODEL FOREST ASSOCIATION

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A Survey of  
**DISTURBED LANDS**  
*within*  
**The Prince Albert Model Forest**  
*to Assess Productivity*

*prepared for*  
**Prince Albert Model Forest Association Inc.**  
May 24, 1996



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## SUMMARY

Forest areas disturbed by timber harvesting were surveyed to assess the density and productivity of regenerating trees species and to investigate the relationships among tree density, productivity and other site characteristics.

A modified regeneration survey technique was applied to sample 1,955 plots from four basic strata: 7P (1961-1980, disturbance, planted), 7N (1961-1980, disturbance, not planted), 8P (1981-1990, disturbance, planted), 8N (1981-1990, disturbance, not planted). Data on the number, size and species of trees, the quantity and species of competing vegetation, soil texture, soil drainage and coarse woody debris were collected. Sample plot data were further stratified by soil texture classes and estimates of basal area, tree density and productivity were compiled for each stratum.

### Regeneration Density

Density was compared among sites in terms of simple density (trees/ha) and Stand Density Index (SDI), which is the number of trees per hectare at a standard average DBH (10 cm in this case).

Two general observations regarding stand density were made. These were that the density of the planted sites was significantly higher than that of the naturally regenerated sites and that the ratio of hardwoods/conifers on planted sites (0.8:1) was much lower than that on naturally regenerated sites (1.6:1). This is explained by the planting of white spruce and jack pine which tends to increase the density of these two species and reduces the density of competing hardwood species relative to naturally regenerated sites.

SDI was used to compare density of trees among sites of different ages. The mean SDI of the 1961-1980 strata, 2,090 trees/ha, was substantially higher than the SDI of the 1981-1990 strata, 950 trees/ha. This increase in SDI with time since disturbance is more pronounced in naturally regenerated sites relative to planted sites and occurs more within the hardwood component. This leads to the conclusion that the increase in SDI is probably due to the "filling in" of growing space, primarily by hardwoods, that has occurred on the older sites.

SDI estimates from this study were compared to SDI values for stands published in other studies. The results showed that in the 1981-1990 strata, the SDI means for sites of all species were generally much lower than the published SDI values. In the 1961-1980 strata, the SDI means for black spruce and white spruce sites were lower than published levels, the mean SDI for aspen sites was marginally lower and the mean SDI for jack pine sites was above published levels.

Analysis of variance of the SDI values stratified by various site factors showed that SDI varied significantly among different soil drainage classes and soil organic depth classes. The highest densities occurred on well and moderately well drained sites and density was highest on sites with the organic matter greater than 10 cm thick.

### Site Productivity

Three expressions of productivity were compared among strata. These were: 3-year height increment, 10-year basal area increment (single tree), and site index at age 50 (SI-50).

Three-year height growth did not vary appreciably between stratum while 10-year basal area increment was on average higher in planted site compared to naturally regenerated sites. This difference was more pronounced in the 1981-1990 strata than in the 1961-1980 strata.

The use of SI-50 was explored as a means of comparing the productivity of sites occupied by trees of different ages. A comparison of SI-50 estimates among strata showed that SI-50 did not vary significantly with disturbance period or site treatment. However, SI-50 did differ significantly among soil drainage classes and soil organic depth classes. Among texture classes, the highest SI-50 estimates were obtained from plots with coarse texture soils (sands and sandy loams) relative to fine and very fine textures soils. The SI-50 trends relative to soil organic thickness varied with species. These results were evaluated with caution since the SI estimates were generated from functions for mature trees and were suspected of being dependent on tree density.

SI-50 estimates for four species were compared to values for average stands cited in other studies. The estimates for jack pine in all strata fell within the range published by Kabzems and Kirby (1956). The SI-50 estimates for white spruce in all but the 7P strata were below the range published by Kabzems (1971) and the SI-50 estimates for aspen in all strata were just below range published by Kirby et al. (1957).

The final conclusion was that overall plantation basal area and SDI are equivalent to natural stands 9 years older, on the average.

# **TABLE OF CONTENTS**

List of Tables and Figures .....	v
<b>1. INTRODUCTION .....</b>	<b>1</b>
<b>2. METHODOLOGY .....</b>	<b>1</b>
<b>2.1 SAMPLING PLAN .....</b>	<b>1</b>
2.1.1 Base Population: .....	1
2.1.2 Sampling Objective .....	3
2.1.3 Sampling Distribution: .....	3
2.1.4 Plot Size .....	3
2.1.4.1 Outer Plot .....	3
2.1.4.2 Inner Plot .....	3
2.1.5 Attributes Sampled .....	4
2.1.5.1 Outer Plot .....	4
2.1.5.2 Inner Plot .....	4
2.1.6 Tally Sheet Design .....	4
<b>2.2 CONDUCT OF THE FIELD SURVEY .....</b>	<b>4</b>
2.2.1 Attribute Measurements .....	5
2.2.2 Sampling Error .....	6
2.2.3 Data entry .....	6
<b>2.3 STATISTICAL ANALYSIS .....</b>	<b>6</b>
2.3.1 Data Compilation .....	6
2.3.2 Development of Sample Estimates .....	6
2.3.3 Statistical Comparison of Estimates .....	7
<b>3. PROJECT REPORT .....</b>	<b>7</b>
<b>3.1 RESULTS .....</b>	<b>7</b>
3.1.1 Stratification and Summary of Estimates .....	7
3.1.2 Data Transformation .....	9
3.1.3 Sample Estimates .....	12
3.1.4 Statistical Comparison of Estimates .....	18
<b>4. FURTHER DISCUSSION .....</b>	<b>23</b>
<b>4.1 THE SAMPLING ERROR .....</b>	<b>23</b>
<b>4.2 GROUND VEGETATION .....</b>	<b>24</b>
<b>4.3 SOILS .....</b>	<b>24</b>
<b>4.4 STUDY CONDUCT .....</b>	<b>24</b>
<b>5. CONCLUSIONS AND RECOMMENDATIONS .....</b>	<b>25</b>
<b>5.1 CONCLUSIONS .....</b>	<b>25</b>
5.1.1 Study format and methodology .....	25
5.1.2 Conclusions regarding productivity: .....	25
<b>5.2 RECOMMENDATIONS .....</b>	<b>26</b>
<b>REFERENCES .....</b>	<b>27</b>
<b>ASSOCIATED APPENDICES</b>	
1. SAMPLING DISTRIBUTION	
2. TALLY SHEET	
3. DISTURBED LANDS DATABASE STRUCTURE - FIELD DATA ENTRY	
4. DISTURBED LANDS DATABASE STRUCTURE - ANALYSIS	
5. SUMMARY OF STAND DENSITY INDEX VALUES, BA AND SI-50 ESTIMATES BY STRATA AND SAMPLE SPECIES	
6. SUMMARY OF ANALYSIS AND VARIATION RESULTS	

## List of Tables

---

<b>Table 3.1</b>	Summary of the number of sample plots in each of the four basic strata . . . . .	7
<b>Table 3.2</b>	Total basal area per hectare estimates and confidence interval for the four basic strata . . . . .	8
<b>Table 3.3</b>	Stratum means for field measured variables . . . . .	9
<b>Table 3.4</b>	Summary of the number of plots in each of the 12 final strata . . . . .	12
<b>Table 3.5</b>	Stand density index broken down by species for each of the four basic strata . . . . .	13
<b>Table 3.6</b>	Stand density index broken down by species for each of the three soil texture strata . . . . .	13
<b>Table 3.7</b>	Summary of the number of plots in each of the 12 final strata . . . . .	13
<b>Table 3.8</b>	Published SDI values for mature stands of four species . . . . .	14
<b>Table 3.9</b>	Summary of analysis of variance results indicating which site variables had a significant effect on stand density index and three measures of productivity . . . . .	20
<b>Table 3.10</b>	Summary of stand density index estimates broken down by various site factors . . . . .	21
<b>Table 3.11</b>	Summary of SI-50 estimates broken down by various site Factors . . . . .	22

## List of Figures

---

<b>Figure 2.1</b>	Prince Albert Model Forest Key Map . . . . .	2
<b>Figure 3.0</b>	Comparison of Productivity between Planted and Natural Regeneration Strata . . . . .	8
<b>Figure 3.1</b>	Plot of quadratic mean DBH versus stems per hectare on logarithmic scale . . . . .	10
<b>Figure 3.2</b>	Sample tree height plotted against age for jack pine dominated plots compared to SI(50) curves from Cieszewski and Bella (1994) . . . . .	11
<b>Figure 3.3</b>	Box plot of 3-year height increment broken down by the four basic strata . . . . .	15
<b>Figure 3.4</b>	Box plot 10-year basal area increment broken down by the four basic strata . . . . .	16
<b>Figure 3.5</b>	Box plot of site index (height at age 50) broken down by the four basic strata . . . . .	17
<b>Figure 3.6</b>	Box plot of site index (height at age 50) broken down by soil texture strata . . . . .	18

# DISTURBED LANDS - FOREST PRODUCTIVITY SURVEY

## 1. INTRODUCTION

The purpose of the Survey of disturbed lands within the Prince Albert Model Forest, as laid out in the Statement of Work was to: *provide evidence on the effects of forestry practices on forest productivity, woody debris, and understory vegetation.*

The survey took place within the 315,000 ha Prince Albert Model Forest (PAMF). It is located approximately 100 km north of the City of Prince Albert and includes the middle third of Prince Albert National Park, part of Weyerhaeuser Canada's Forest Management Licence Agreement area and the whole of Montreal Lake Cree Nation Reserve land. There are approximately 80,000 hectares of land available for timber management within the Prince Albert Model Forest. A description of the Prince Albert Model Forest, together with its most prominent sustainability challenges, will be found in Bouman et al (1996).

The field survey component was undertaken by Silviba Services Ltd of Prince Albert, Saskatchewan using graduate IRM (Integrated Resource Management) technicians and four forestry staff from Montreal Lake Cree Nation, from July to September 1995. The analysis work was carried out by Dendron Resource Surveys Inc. of Ottawa, Ontario. In addition, Dendron provided technical support with respect to the sampling design.

The main scope of the disturbed lands study was to undertake a survey of forest lands within the PAMF that had experienced disturbance due to harvesting and had either regenerated naturally or had been replanted.

## 2. METHODOLOGY

### 2.1. SAMPLING PLAN

#### 2.1.1 Base Population:

Area harvested 1966-79:	planted: 3159 ha natural: 5207 ha
Area harvested 1979-90:	planted: 4260 ha natural: 7898 ha
	<hr/>
	Total: 20524 ha

The PAMF Association Inc. provided a data base which classified the polygonal cover into three periods of disturbance. This was then used as the basis for the sampling plan. Primary disturbance was clearcut harvesting, with the initial year being 1966. Secondary disturbance, when present, denoted planting. Tertiary disturbance was attached to subsequent cleaning and thinning operations.

**Figure 2.1** Prince Albert Model Forest Key Map

## 2.1.2 Sampling Objective

The sampling plan was derived from the report: "*Plantation Assessment Survey Procedures*" produced for Saskatchewan Environment and Resource Management in 1993, by Silviba Services Ltd. This became the basis for the methodology involved with plantation assessment surveys now in use by that department. In the absence of a pilot project to test statistical variation within and between strata, a sampling objective applied to the average basal area in m<sup>2</sup>/ha, +/- 15%, 19 out of 20 times, softwoods and hardwoods combined, was decided on for all strata combined.

## 2.1.3 Sampling Distribution:

PAMF Association supplied a GIS Key Map of the Model Forest Area together with one set of maps at 1:12,500 scale with the disturbed areas colour themed by decade of disturbance. The polygons were labeled as follows : polyID #, species association, primary and secondary species and year of origin. Included with the maps was associated information listing the disturbed polygons for two time periods, from 1966 to 1979 and from 1980 to 1990.

The basis for the sampling distribution was derived from disturbed polygons sorted into four groups:

- Pre	1980 naturally regenerated polygons	(1966- 1979) .....	7N	.....	731 polygons
- Pre	1980 planted polygons	(1966- 1979) .....	7P	.....	361 polygons
- Post	1980 naturally regenerated polygons	(1980 -1990) .....	8N	.....	1457 polygons
- Post	1980 planted polygons	(1980- 1990) .....	8P	.....	<u>592 polygons</u>
		Total:			3141 polygons

Again, due to the absence of an opportunity to determine the necessary level of sampling intensity (number of plots / polygon) beforehand, an assumption was made which required that 500 polygons were to be sampled. Further, from past experience, it was decided to establish an average of 6 plots per polygon, or 3000 plots altogether. Polygons less than 1 ha were deleted from the population base since these were largely skewed by edge effect and road corridors.

Following the random selection of the polygons to be sampled, the 3000 plots were to be randomly distributed throughout the polygons selected. See Appendix 1.

## 2.1.4 Plot Size

### 2.1.4.1 Outer Plot

A plot size of 8.9 m radius was associated with the sampling intensity identified. Thus a fixed-radius circular plot of this size (1/40 ha) was considered to be the most ergonomically and cost effective of the size ranges available. All large trees ( dbh >9 cm) were sampled in the 8.9 m radius plot.

### 2.1.4.2 Inner Plot

All small trees (dbh 9.0 cm and less) were sampled from a concentric inner plot of 1.78 m radius (1/1000 ha).

## 2.1.5 Attributes Sampled

### 2.1.5.1 Outer Plot

The following information was recorded for the outer plot which had a radius of 8.9 meters from the plot centre and covered an area of 250 m<sup>2</sup>:

- *species association*
- *productive size trees (dbh > 9 cm) tallied by species and 2.0 cm increment dbh class.*
- *one dominant/codominant tree sampled for : total age and total height in m, height in the last 3 years, dbh in cm, 10 year growth.*
- *soil organic layer (by depth)*
- *mineral soil texture (by class)*
- *drainage class and moisture regime as per Saskatchewan forest inventory procedures.*
- *woody debris characteristics*
- *slash cover codes*

### 2.1.5.2 Inner Plot

The following information was recorded for the inner plot which had a radius of 1.78 meters from the plot centre and covered an area of 10.00 m<sup>2</sup>:

- *ground vegetation classified by height and tallied by percentage density of ground cover (shrubs, herbs, grasses, sedges, "mosses/lichens).*
- *small trees (dbh < = 9.0 cm) tallied by root collar diameter.*
- *average root collar basal area*
- *number of stems by species*
- *clump information*

## 2.1.6 Tally Sheet Design (Appendix 2)

The tally sheet was designed to record information from an Inner plot (1.78 m radius) and an outer plot (8.9 m radius). The baseline information recorded on each tally sheet included the following:

*Surveyor's name*  
*Assistant surveyor's name*  
*Date*  
*Index number*  
*Polygon ID number*  
*Plot number*  
*Mapsheet number*

The surveyor was required to identify the stratum ( *7N, 7P, 8N or 8P* ) and also whether the tally sheet was an *original* or a *check plot*.

A separate tally sheet was filled out for each plot within a polygon. Tally sheets were compiled by polygon ID number, checked over by the field supervisor and submitted for data entry.

## **2.2 CONDUCT OF THE FIELD SURVEY**

Field work commenced on July 28, 1995 and was completed by September 15th 1995, as required in the contract. The survey team found that, of the 500 polygons that made up the sample plan, 25 were

eliminated by the MONDAY fire that occurred during the spring and early summer of 1995. Also, 78 polygons were found to be inaccessible both by quad or on foot, due to flooding. The flooding was a result of the heavy rains that occurred during the month of August, following the biggest forest fire season on record. Also, 11 were listed in the database but not on the maps and 3 were found to form part of a golf Course.

Check plots were done but most quality control was done after a review of plot data. Where data appeared to be incompatible with expected results, plots were remeasured. The largest errors were found through the absence of an adequate number of sample tree heights. A significant group of plots was remeasured to pick up more tree height measurements.

Table 3.1 shows that 1955 plots were used in the analysis to follow; although, 2185 plots were established in the field.

### 2.2.1 Attribute Measurements

In the field, detailed information concerning the smaller diameter (< 9.1 cm) hardwood and softwood species, ground vegetation according to species and classification was taken from within the inner plot radius. Information concerning the larger diameter hardwood and softwood species (> 9 cm), soils texture and drainage, woody debris and slash cover codes was taken from the outer plot. Classifying of ground vegetation presented no serious errors in identification. Some initial training was necessary, but the selection of reference texts available enabled the crews to check their decisions as they proceeded.

It was obvious that 3-year height growth measurements for aspen, birch and cottonwood probably lacked accuracy since they do not exhibit recognizable internodal growth.

Also, 10-year radial increment for hardwoods takes skill and experience. Most research methodology involves the removal of cross-sections for later treatment in the lab.

#### Woody debris information (5 cm+ in diameter):

Information on woody debris covering the ground surface was recorded as part of the information collected for the outer plot. The information collected under the heading *Woody Debris Characteristics*, included the following : percentage bolewood, percentage branches and tops and the average depth of fine fuels in centimetres. Fuel loading was ranked according to an informal calibration guide set in place for the survey teams prior to the start of the project. Given budget limitations, it was not possible to improve accuracy or remove the high degree of variations anticipated between teams.

The methodology for the collection of Woody Debris information was developed from the following studies: *Economic Feasibility of Utilizing Logging Slash and Fire - Killed Timber For Energy*; ENFOR Project P-379, March 1991, Reid, Collins and Associates, in association with Silviba Services Ltd. Also, with permission, refer to a study on wastewood volumes after harvesting, undertaken by Silviba Services Ltd for Mistik Management Ltd., Dec., 1992. It should be noted that the sampling of woody debris, 5 cm in diameter and greater at the centre of a stem, was done prior to silvicultural treatment in that study.

### Soils Information:

This included soil surface descriptions in which soil litter, organic and mineral horizons were identified, measured and classified by texture (Code : 0.5 > 5.0). The soil moisture regime was determined and classified according to drainage class (Code : 1 >6)

#### 2.2.2 Sampling Error

As was noted earlier, field conditions necessitated certain adjustments to the sampling plan. Destruction of plots as a result of the MONDAY fire in early July 1995 and flooding of areas, due to heavy rains later in the month, were not anticipated and made adjustments to the sampling plan unavoidable. Despite the fact that sampling intensity was somewhat reduced when Dendron undertook the analysis work for the disturbed sites it was found that the sampling error for the four strata combined ( 4.7%) was well within the target of  $\pm 15\%$  19 out of 20 times. Given a CV of > 100%, some possible concerns are raised later in this report.

#### 2.2.3 Data entry

As the tally sheets were completed by the field crews they were compiled by the team leader, checked over and forwarded to the Silviba Office in Prince Albert for data entry. Before being entered the individual tally sheets were checked over to ensure that the polygon and individual map numbers had been correctly filled in by the field team. Dendron developed a special menu driven data input program that allowed the technician responsible for data entry to input the field information directly into dBase IV. Periodically, after verification, the data was backed up on diskette and shipped to Dendron in Ottawa for further analysis. See Appendix 3 for outline of data base input structure.

### **2.3 STATISTICAL ANALYSIS**

#### 2.3.1 Data Compilation

The validated field data were assembled into four database files which were related to each other via a common plot identity number. One file contained general information on each plot including location, sample date, polygon number, stratum, sample tree measurements, competition levels and woody debris. A second file contained data on the overstorey tree tally, a third contained data on the understorey vegetation tally and, a fourth contained data on clumps of regenerating trees. See Appendix 4 for outline of data base analysis structure.

#### 2.3.2 Development of Sample Estimates

Stocking estimates were compiled for each stratum to determine if the sampling objective, to estimate total basal area to within  $\pm 15\%$  19/20 times, was achieved for each stratum.

Alternative stocking measures were compared to determine which one was best for comparing the stocking of stands of different ages and species. Similarly, alternative measures of site productivity were compared to determine which were best for comparing the productivity of stands of different ages and species composition.

Multiple regression and correlation analyses were used to determine which site variables correlated strongly with stocking and productivity. Variables with strong correlations were then examined for use in further stratification of sample plots.

Once a final stratification scheme was established, estimates of regeneration density and site productivity were calculated and reported with mean values for tree height, age and competition class of each stratum.

### 2.3.3 Statistical Comparison of Estimates

Analyses of Variance (ANOVA) were carried out to explore the relationships between regeneration density, productivity and various site characteristics such as soil drainage, depth of soil organic matter and competition level. The ANOVA technique provided a systematic way of studying the variability within the sample population (stands) and to determine which site variables (soil drainage, competition, etc.) had a significant independent effect on density or productivity either individually or in combination.

## 3. PROJECT REPORT

### 3.1 RESULTS

#### 3.1.1 Stratification and Summary of Estimates

Data from 1,955 sample plots were grouped into the four basic sample strata. Table 3.1 provides the distributions of plots among these strata.

**Table 3.1** Summary of the number of sample plots in each of the four basic strata.

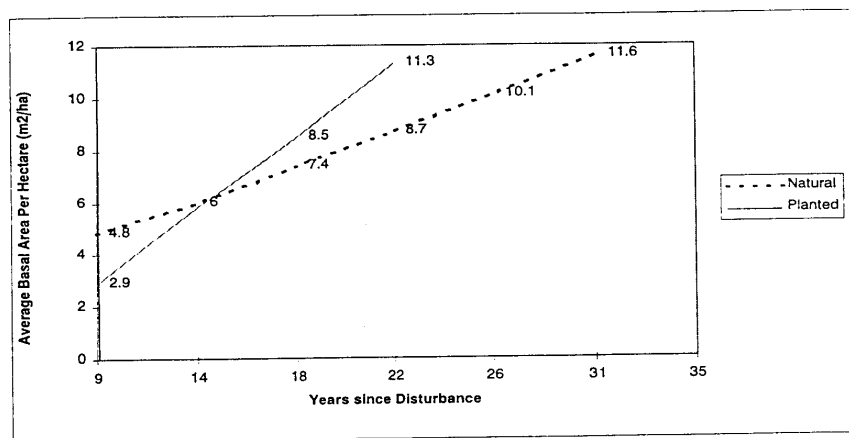
Stratum	Code	No. of Plots
Pre-1980 planted (1961-1980)	7P	451
Pre-1980 naturally regenerated (1961-1980)	7N	303
Post-1980 plant (1981-1990)	8P	804
Post-1980 naturally regenerated (1981-1990)	8N	397
TOTAL		1,955

Basal area estimates and confidence intervals for the four basic strata are provided in Table 3.2. This table shows that the sampling objective, to estimate the total basal area per hectare for each stratum to within  $\pm 15\%$  19/20 times, was achieved.

**Table 3.2** Total basal area per hectare estimates and confidence interval for the four basic strata.

Strata	No. of plots	Avg. Age (years)	Mean basal area/ha	Coefficient of variation	Standard Error	Confidence Interval @95% Level
7N	451	31	11.6m <sup>2</sup>	70%	0.38	±6.5%
7P	303	22	11.3m <sup>2</sup>	66%	0.43	±7.4%
8P	804	9	2.9m <sup>2</sup>	121%	0.12	±8.3%
8N	397	14	6.0m <sup>2</sup>	97%	0.29	±9.6%
Total	1,955		6.8m <sup>2</sup>	104%	0.16	±4.5%

Amended: Oct. 1996



**Figure 3.0** Comparison of Productivity between Planted and Natural Regeneration Strata (All species)

The foregoing chart, developed from interpolated values, implies that basal area production is almost 40 per cent greater for plantations as opposed to natural regeneration, by age 22 years, for all plots combined.

From the sample of 1,955 plots, mean values of the density, productivity and other measured variables were compiled for each of the four basic strata. These are presented in Table 3.3 below:

**Table 3.3** Stratum means for field measured variables

Descriptive Variable	Stratum Mean			
	Natural 1961-1980	Planted 1961-1980	Natural 1981-1990	Planted 1981-1990
Number of plots	451	303	804	397
Age in years	31	22	9	14
Regeneration: Stems/ha	10,636	10,650	12,311	11,851
Large Tree: Stems/ha	223	153	2	9
Total Stems/ha	10,860	10,803	12,313	11,860
Regeneration: DBHq	3.45	3.61	1.75	2.61
Large Tree: DBHq	14.38	11.76	14.31	10.54
Total: DBHq	5.02	4.14	1.76	2.68
3-Yr Height Growth (M)	0.6	0.7	0.6	0.6
10-Yr Basal Area Increment (cm <sup>2</sup> )	41.7	43.7	9.4	34.2
Species Composition				
Aspen	52%	38%	51%	31%
Balsam Poplar	0%	0%	9%	0%
White Birch	6%	8%	6%	3%
Jack Pine	17%	34%	31%	52%
White Spruce	7%	7%	6%	10%
Black Spruce	11%	6%	1%	0%
Balsam Fir	4%	4%	0%	0%
Larch	1%	0%	1%	0%
Soil Texture	Mod. Coarse	Mod. Coarse	Mod. Coarse	Coarse
Soil Drainage	Mod. Well	Well	Mod. Well	Well
Slash Load (m <sup>3</sup> /ha)	<5	5 - 20	5 - 20	5 - 20

### 3.1.2 Data Transformation

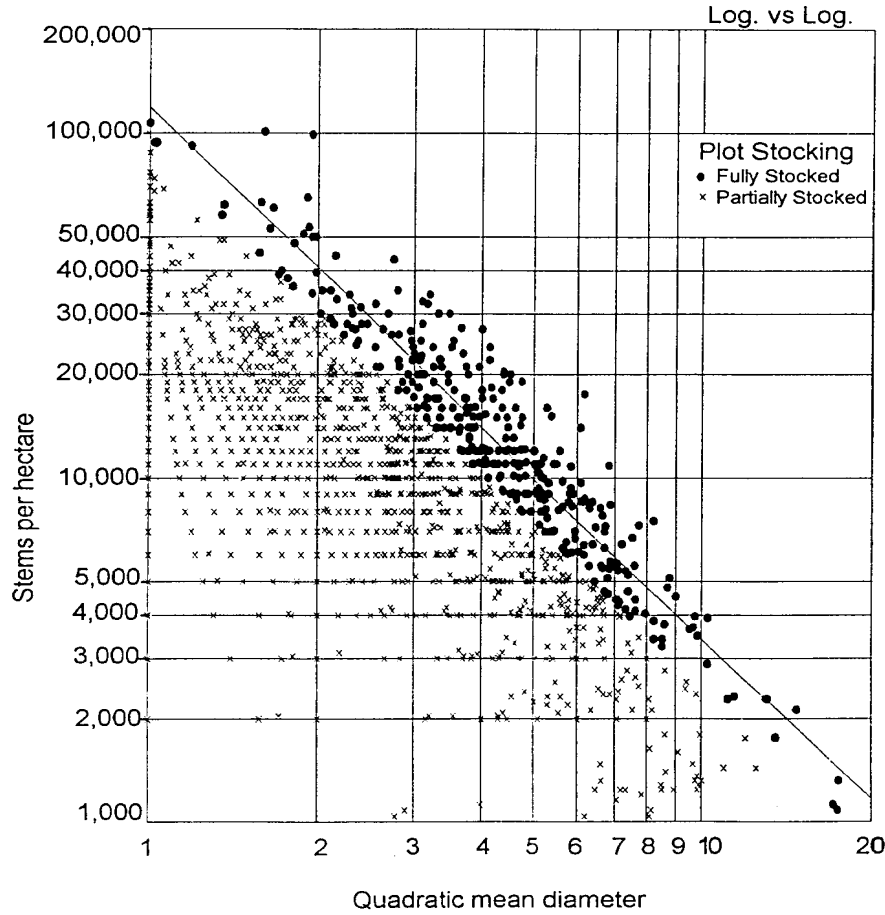
In addition to simple trees per hectare, stand density was also compared in terms of Stand Density Index (SDI), which is the number of trees per hectare a stand would have at a standard average DBH (10 cm in this case). SDI is age-independent and thus provided a means for comparing the density of trees between sites of different ages.

SDI takes advantage of a predetermined limiting relationship between the density and size of trees occupying a site. In fully stocked even-aged stands, this relationship between density and mean tree diameter is often linear when plotted in logarithmic coordinates. This is demonstrated in Figure 3.1 which is a logarithmic chart of trees per hectare (N) and quadratic mean DBH (D<sub>q</sub>) of all sample plots. Those plots deemed to be fully stocked are plotted using the • symbol and all other, partially stocked, plots are plotted using the x symbol. A line is fitted to the fully stocked plots. The slope of the line is -1.55 which is consistent with the

relationships observed by Reineke (1933) and others for a number of species. From this relationship the following, index first proposed by Reineke (1933), was developed:

$$SDI=N(10/D_q)^{-1.55}$$

Equation I and illustrated in Figure 3.1



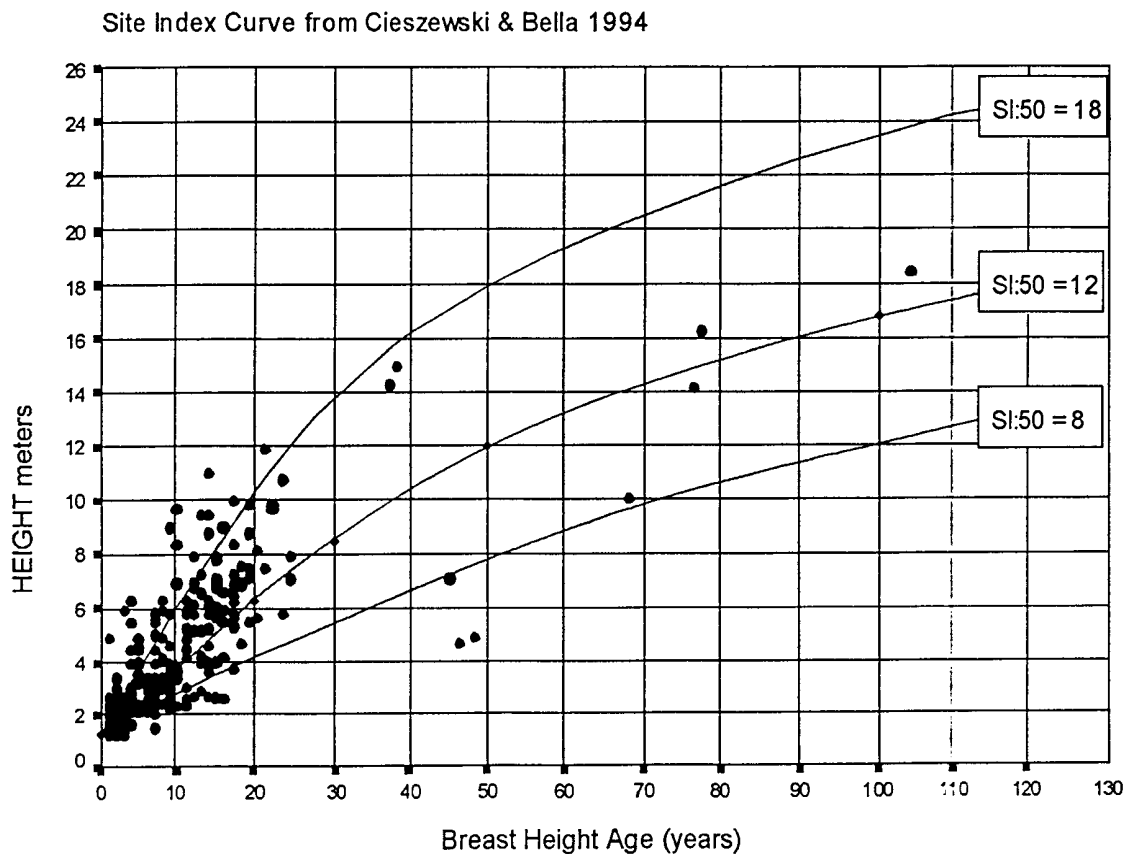
**Figure 3.1** Plot of quadratic mean DBH versus stems per hectare on logarithmic scale

Two measures of tree growth, 3-year height increment and 10-year basal area increment, were compiled from trees sampled at each plot. These measures are dependent on tree age and

species and thus, may be unsuitable for comparing the productivity of sites occupied by trees of different species or age.

Estimates of site index at age 50 (SI-50) were compiled for plots dominated by jack pine, white spruce or aspen. SI-50 is the predicted height of a tree at a standard age of 50 and was calculated from sample measurements using polymorphic site index curves developed for these species by Cieszewski and Bella (1994). Figure 3.2 is a graph of the age-height relationship for sample trees from jack pine-dominated plots compared to three index curves.

SI-50 estimates were calculated to explore their value for comparing the productivity of sites occupied by trees of the same species but at different ages. The absolute value of the SI-50 were evaluated with caution since they were derived from functions developed for mature trees and since site index may be dependent on site stocking.



**Figure 3.2**

Sample tree height plotted against age for jack pine dominated plots compared to SI(50) curves from Cieszewski and Bella (1994).

Multiple linear regression was used to examine the relationships between the independent site variables (ie. primary species, soil texture, soil drainage) and the dependent variables of SDI

Multiple linear regression was used to examine the relationships between the independent site variables (ie. primary species, soil texture, soil drainage) and the dependent variables of SDI and SI-50 with the objective of determining which site variables would be useful to further stratify the sample plots. The results indicated that soil drainage, soil texture and primary species explained more of the variation in SDI and SI-50 than any other site variable tested. Since soil drainage and soil texture were highly correlated and statistical analysis required that no more than 12 strata be used, the four basic strata were further subdivided into three soil texture classes. These three soil classes are defined as follows:

Texture Class	Soil Textures
Coarse Texture	coarse to fine sand, sandy loam
Fine Texture Soil	very fine sands, silty loam, sandy clay
Very Fine Texture Soil	silty clay, clay, organic

Plots were grouped by the four original strata (period of disturbance and type of treatment) and the three texture classes. The number of plots in each of the resulting strata is shown in Table 3.4

**Table 3.4** Summary of the number of plots in each of the 12 final strata.

BASIC STRATUM	SOIL STRATUM	CODE	NO OF PLOTS
Planted (1961 - 1980)	Course Texture	7P,c	91
Planted (1961 - 1980)	Fine Texture Soil	7P,f	304
Planted (1961 - 1980)	Very Fine Texture Soil	7P,vf	56
Natural (1961 - 1980)	Course Texture	7N,c	91
Natural (1961 - 1980)	Fine Texture Soil	7N,f	183
Natural (1961 - 1980)	Very Fine Texture Soil	7N,vf	29
Planted (1981 - 1990)	Course Texture	8P,c	249
Planted (1981 - 1990)	Fine Texture Soil	8P,f	387
Planted (1981 - 1990)	Very Fine Texture Soil	8P,vf	168
Natural (1981 - 1990)	Course Texture	8N,c	172
Natural (1981 - 1990)	Fine Texture Soil	8N,f	140
Natural (1981 - 1990)	Very Fine Texture Soil	8N,vf	85

### 3.1.3 Sample Estimates

#### Stand Density Index

Mean stand density index broken down by species is provided for each of the basic strata in Table 3.5 and for each of the soil strata in Table 3.6. Tabular summaries of these data are provided in Appendix 5.

**Table 3.5** Stand density index broken down by species for each of the four basic strata.

STRATUM	Aspen	White Birch	Balsam Poplar	Jack Pine	White Spruce	Black Spruce	Balsam Fir	Larch	Total SDI
Natural 1961 - 1980	1117	133	31	354	145	176	104	11	2072
Planted 1961 - 1980	777	163	67	786	129	82	112	0	2116
Natural 1981 - 1990	406	48	29	229	36	10	2	6	766
Planted 1981 - 1990	448	30	31	720	83	7	0	3	1323

**Table 3.6** Stand density index broken down by species for each of the three soil texture strata.

SOIL TEXTURE	Aspen	White Birch	Balsam Poplar	Jack Pine	White Spruce	Black Spruce	Balsam Fir	Larch	Total SDI
Course	592	100	71	505	115	14	19	9	1426
Fine	719	88	16	444	65	72	70	2	1477
Very Fine	465	31	31	333	92	98	2	10	1061

The SDI of the 1961-1980 strata were substantially higher than that of the 1981-1990 strata. Also, the SDI of planted strata were somewhat higher than those of the naturally regenerated strata. When species proportions were compared between strata it was observed that the proportion of hardwood was lower in the planted strata relative to the naturally regenerated strata.

SDI was on average higher for sites with fine and coarse soil textures relative to sites with very fine soil textures. The species proportions also differed between soil texture strata. For instance, black spruce made up a greater proportion of the average stand in the "very fine" stratum compared to that of the "fine" and "coarse" strata.

Table 3.7 lists the mean SDI at a 10 cm DBH standard and the mean SDI at a 25 cm DBH standard for all plots broken down by dominant species and the four basic strata. Table 3.8 lists the mean SDI values for black spruce, white spruce, jack pine and aspen stands cited in previous surveys of mature stands.

**Table 3.7** Summary of the number of plots in each of the 12 final strata.

STRATUM	SDI @10cm	SDI @25cm	No. of Plots	STRATUM	SDI @10cm	SDI @25cm	No. of Plots
Natural 1961 - 1980				Natural 1981 - 1980			
Balsam Fir	2456	593	20	Balsam Fir	1392	337	2
Balsam Poplar	1714	414	8	Balsam Poplar	714	172	32
Black Spruce	1612	390	47	Black Spruce	248	60	5
Jack Pine	2070	500	78	Jack Pine	805	195	235
Aspen	2222	537	241	Aspen	849	205	402
Larch	2002	484	2	Larch	608	147	9
White Birch	1906	461	25	White Birch	858	207	44
White Spruce	1884	455	25	White Spruce	522	126	29
No Trees	0	0	5	No Trees	0	0	46
Total	2072	501	451	Total	766	185	804
Planted 1961-1980				Planted 1961-1980			
Balsam Fir	2761	667	12	Balsam Fir	940	227	11
Balsam Poplar	2332	563	7	Balsam Poplar	-	-	1
Black Spruce	1068	258	12	Black Spruce	1426	345	210
Jack Pine	2371	573	111	Jack Pine	1495	361	125
Aspen	2004	484	116	Aspen	761	184	13
White Birch	1999	483	27	White Birch	510	123	31
White Spruce	1637	396	18	White Spruce	0	0	6
Total	2116	511	303	Total	1323	320	397
				All Strata Total	1389	336	1955

**Table 3.8** Published SDI values for mature stands of four species.

Stand Species	SDI @10 cm	SDI @25 cm	Source
black spruce	2048-4552	495-1100	Kabzems (1953)
white spruce	2145-3205	495-740	Kirby (1962)
jack pine	2236	415	Kabzems & Kirby (1956)
aspen	2891	667	Kirby et. al. (1957)

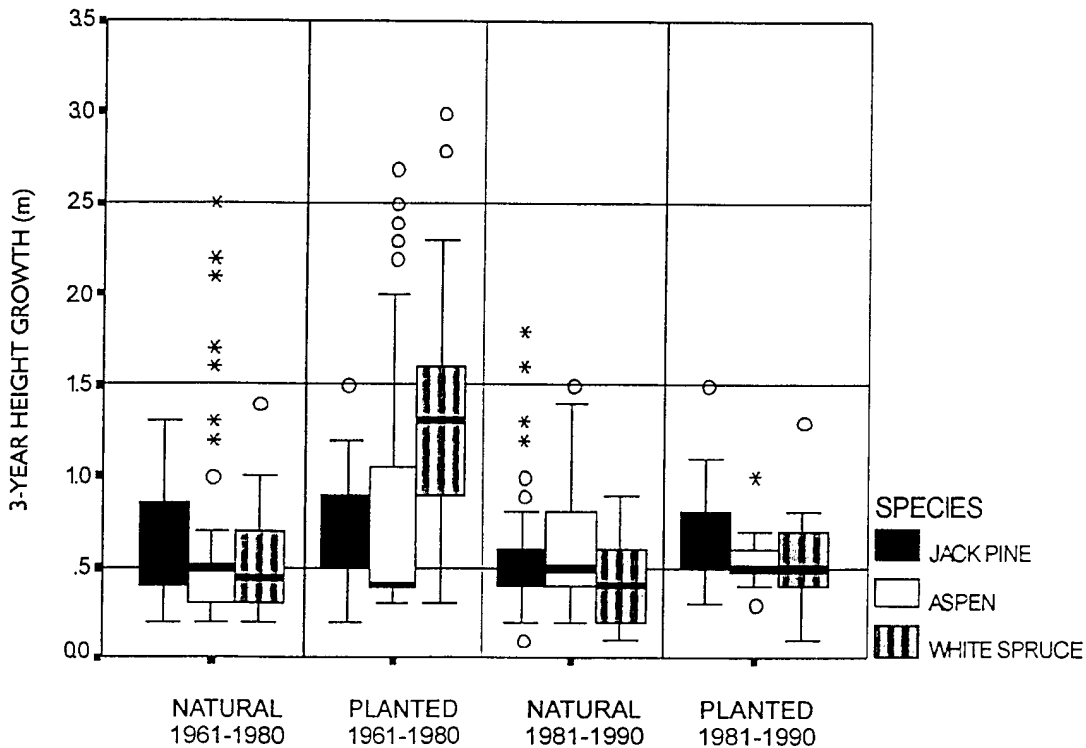
When the SDI estimates for spruce, pine and aspen from this study were compared to the published estimates in Table 3.8, it was observed that:

- in the 1981-1990 strata, stands of spruce, pine and aspen were lower than the published levels, and
- in the 1961-1980 strata, black spruce and white spruce stands were of lower stocking than published estimates, aspen stands were marginally lower and jack pine stands were stocked above published estimates.

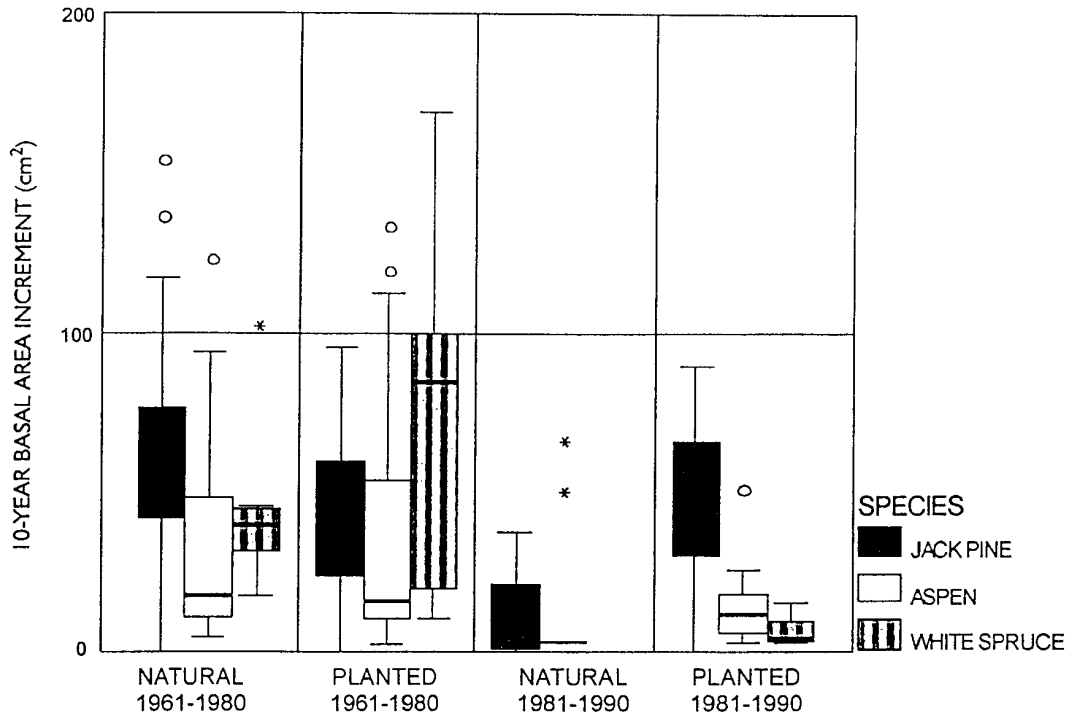
Stand Productivity

Three expressions of productivity were calculated for each plot and compared among strata. These were: 3-year height increment, 10-year basal area increment (single tree), and site index. Since all three measures were species dependent, comparisons were made with samples grouped by species.

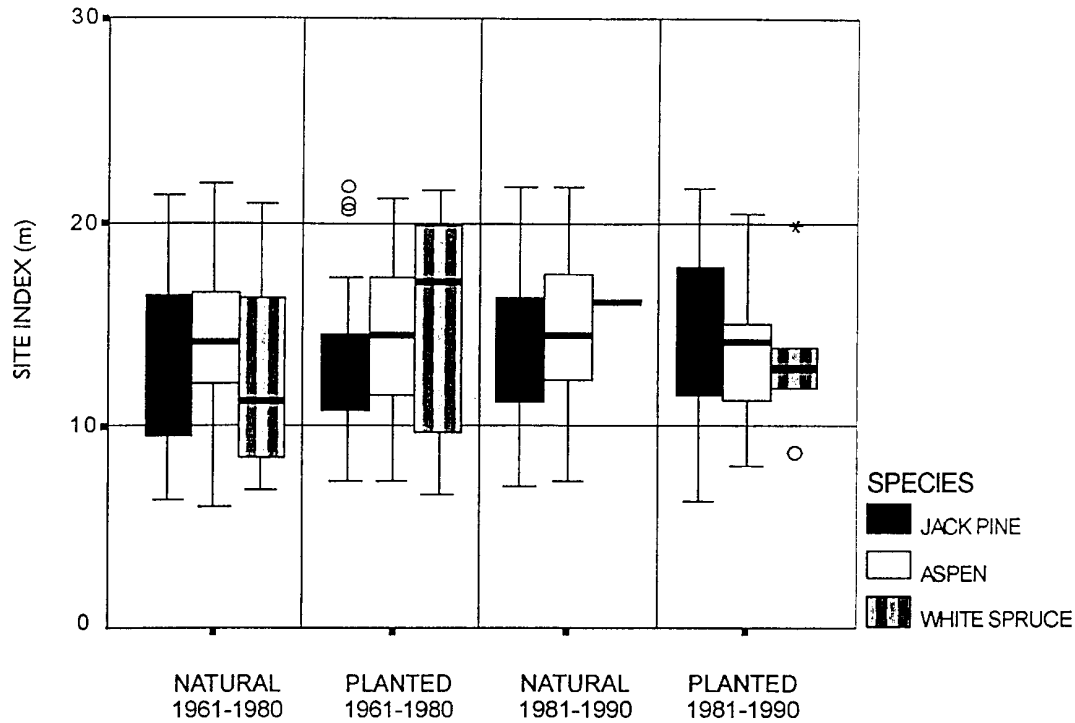
Box plots showing the distribution of each measure broken down by species and strata are shown in Figure 3.3, Figure 3.4 and Figure 3.5, respectively. In these plots, the thick horizontal line in each box indicates the median SI-50 values, the boxes indicate the 25th and 75th percentiles and the ○ and \* indicate extreme values.



**Figure 3.3** Box plot of 3-year height increment broken down by the four basic strata



**Figure 3.4** Box plot 10-year basal area increment broken down by the four basic strata.

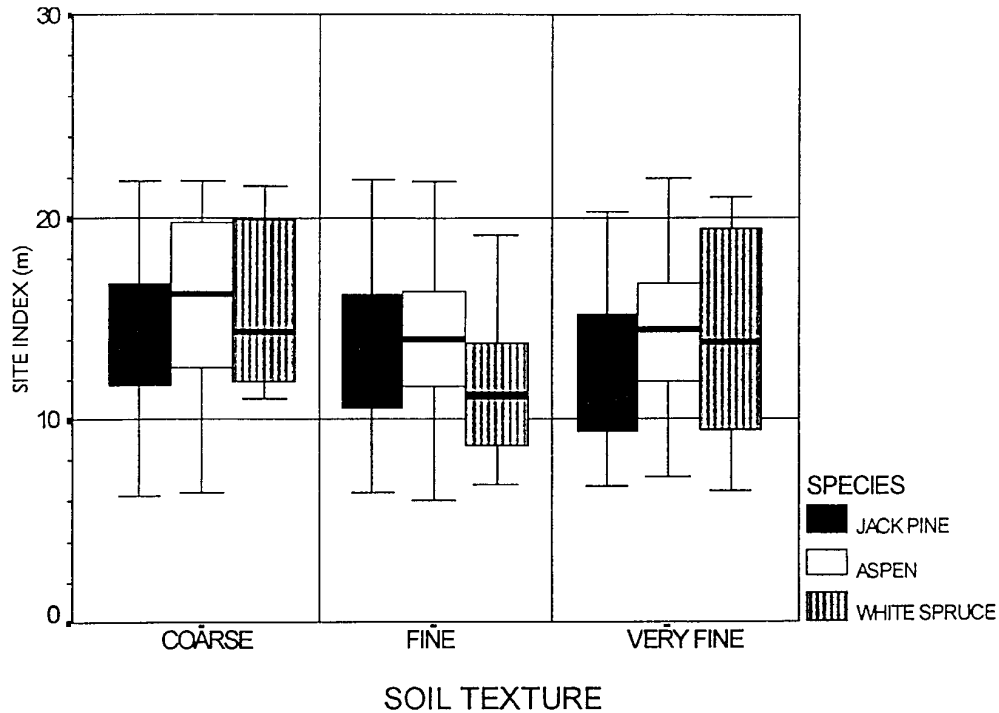


**Figure 3.5** Box plot of site index (height at age 50) broken down by the four basic strata.

In all strata, 10-year radial increment and 3-year height growth were much more variable than SI-50 and showed signs of being age dependent. Although the SI-50 estimates were less variable and, theoretically, age-independent, they were evaluated with caution since they were derived from functions developed for older trees.

Means of the three productivity estimates for three species were compared among strata. Height growth and basal area increment were found to be higher in planted sites relative to natural sites. Also, mean height growth was generally higher in the 1961-1980 strata relative to the 1981-1990 strata. With the exception of white spruce, SI-50 did not vary appreciably between natural and planted strata or between the 1961-1980 and 1981-1990 strata.

Figure 3.6 is a box plot showing the distribution of site index estimates for plots stratified by soil texture class.



**Figure 3.6** Box plot of site index (height at age 50) broken down by soil texture strata.

### 3.1.4 Statistical Comparison of Estimates

The relationships between the productivity and density of trees and various site factors were explored using analysis of variance. The site factors analyzed included period of disturbance, treatment type, soil texture, soil drainage, soil organic depth and vegetative competition class. Groups for each of these factors are defined below:

<u>Disturbance period</u>	<u>Plots</u>	<u>Soil drainage</u>	<u>Plots</u>
1961-1980	754	rapid	28
1981-1990	1201	well	766
		mod. well	1034
<u>Treatment Type</u>	<u>Plots</u>	imperfect-poor	127
planted	1255	<u>Soil Organic Depth</u>	<u>Plots</u>
natural	700	0-5 cm	1462
<u>Soil texture</u>	<u>Plots</u>	6-10 cm	414
coarse	603	> 10 cm	79
fine	1014		
very fine	338		

<u>Vegetative Comp.</u>	<u>Plots</u>
light	680
moderate	934
high	205
severe	42

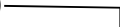

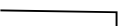

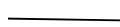


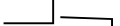

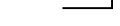


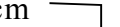
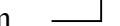
The results of the ANOVA for SDI and SI-50 are presented in Table 3.9. The symbol \*\* is used to indicate independent variables (site factors) which had a highly significant effect on SDI or SI-50. This means that if there is actually no difference among factors the probability that the difference can be explained by chance was 0.01 or less. The symbol \* indicates factors which had a significant effect (probability of a difference due to chance was between 0.01 and 0.05) and the symbol ○ indicate factors that did not have a significant effect (probability of a difference due to >0.05). The detailed reports on the ANOVA are provided in Appendix 6.

Significant differences were identified among the mean SDI of plots grouped by the period of disturbance, type of treatment and depth of soil organic matter. Significant differences were also identified among the mean SI-50 of plots grouped by soil drainage and depth of organic matter.

Where significant differences were found among group means, a multiple comparison procedure was performed to determine pairs that differed significantly. The results are provided in Table 3.9 where lines are drawn between group pairs with significantly different means ( $P < 0.05$ ).

A complete listing of mean SDI and SI-50 for groups of all site factors are provided in Table 3.10 and Table 3.11, respectively. In both tables, the estimate means for groups with fewer than 10 plots should be viewed with caution.

**Table 3.9** Summary of analysis of variance results indicating which site variables had a significant effect on stand density index and three measures of productivity.

GROUPING VARIABLE	DEPENDENT VARIABLE			
	SDI		SI	
Period	99	1961 - 1980  1981 - 1990 	●	
Treatment	99	Planted  Natural 	●	
Soil Texture	●		9	Course  Fine  V. Fine
Soil Damage	99	Rapid  Well  Mod. Well  Imperfect 	●	
Organic Depth	9	0 - 5 cm 6 - 10 cm  > 10 cm 	9	0 - 5 cm 6 - 10 cm  > 10 cm 
Vegetative Competition Class	●		●	
<p>● main effect not significant (F Prob. &gt;0.05)            9 main effect significant (F Prob. &gt;0.01 and ≤ 0.01)            99 main effect highly significant (F Prob. ≤ 0.01)</p> <p>Lines connect groups with significantly different means (F Prob. = 0.05) from post hoc multiple comparison test</p>				

**Table 3.10** Summary of stand density index estimates broken down by various site factors.

Summaries of Stand Density Index				
Site Factor	Group	Mean	Std. Dev.	Plots
Period Of Disturbance	1961-1980	2090	1257	754
	1981-1990	950	959	1201
Type Of Treatment	Natural	1235	1174	1255
	Planted	1666	1246	700
Soil Texture	Coarse	1426	1190	603
	Fine	1477	1242	1014
	Very Fine	1061	1138	338
Soil Drainage	Rapid	1173	1356	28
	Well	1564	1317	766
	Mod. Well	1338	1149	1034
	Imperfect	806	820	127
Soil Organic Matter	0-5 Cm	1379	1224	1462
	6-10 Cm	1351	1167	414
	>10 Cm	1775	1301	79
Vegetative Competition	Light	1367	1247	680
	Moderate	1355	1164	934
	High	1427	1264	205
	Severe	1743	1126	42
For Entire Population		1389	1218	1955

**Table 3.11** Summary of SI-50 estimates broken down by various site Factors.

<b>Summaries of Site Index 50</b>					
Site Factor	Species	Group	Mean	Std. Dev.	Plots
Period Of Disturbance	Jp	1961-1980	13.29	3.61	99
		1981-1990	14.02	3.96	141
	Ta	1961-1980	14.29	3.89	181
		1981-1990	14.56	3.62	135
	Ws	1961-1980	12.95	4.99	26
		1981-1990	13.53	3.12	9
Type Of Treatment	Jp	Natural	13.59	3.84	117
		Planted	13.85	3.83	123
	Ta	Natural	14.46	3.87	215
		Planted	14.29	3.59	101
	Ws	Natural	12.43	4.49	21
		Planted	14.11	4.60	14
Soil Texture	Jp	Coarse	14.45	3.51	92
		Fine	13.42	3.95	116
		Very Fine	12.73	4.02	32
	Ta	Coarse	15.83	4.26	58
		Fine	14.00	3.61	211
		Very Fine	14.45	3.49	47
	Ws	Coarse	15.94	4.26	9
		Fine	11.65	3.75	21
		Very Fine	14.07	6.23	5
Soil Drainage	Jp	Rapid	13.61	2.85	9
		Well	13.40	4.12	113
		Mod. Well	14.13	3.51	114
		Imperfect	11.34	5.51	4
	Ta	Rapid	15.46	3.55	6
		Well	14.26	3.72	178
		Mod. Well	14.71	3.82	113
		Imperfect	13.65	4.16	19
	Ws	Well	12.34	4.19	21
Mod. Well		14.20	4.98	12	
Imperfect		14.48	7.02	2	
Soil Organic Matter	Jp	0-5cm	13.79	3.77	209
		6-10cm	13.29	4.25	31
	Ta	0-5 cm	14.56	4.01	210
		6-10 cm	13.80	3.17	95
		>10 cm	16.72	2.72	11
	Ws	0-5 cm	13.85	4.29	18
6-10 cm		11.40	4.89	10	
>10 cm		13.60	4.72	7	

Vegetative Competition	Jp	Light	13.80	3.93	83
		Moderate	13.86	3.75	122
		High	14.29	4.24	18
		Severe	10.75	3.39	2
	Ta	Light	14.53	3.95	85
		Moderate	14.26	3.75	161
		High	14.16	3.70	47
		Severe	15.62	3.33	13
	Ws	Light	11.87	3.96	17
		Moderate	13.55	4.92	12
		High	20.24	1.13	2
		Severe	10.31	1.12	2

#### 4. FURTHER DISCUSSION

A number of issues remain to be explored further:

##### 4.1 THE SAMPLING ERROR:

Alternatively, the sampling objective in basal area terms could be based on non-parametric statistics. The dynamics of forest renewal, with extreme variations in both stocking and stem density inherently evident, are displayed through tree density ranging from 0 to 70,000 stems/ha. Also, the dynamics of species interaction wherein the presence of poplar increases biomass levels significantly, adds complexity to the analysis of ecosystem attributes at a time of rapid change.

Accordingly, with the 285 polygons and 1955 plots used in the analytical data base, percent stocking was derived from assuming that any inner plot greater than 0 m<sup>2</sup>/ha for basal area was 100% stocked. Thus, 1864/1955 plots were stocked, or 95.3%. A formula used in the Alberta Regeneration Survey manual as an alternative was then applied as follows to determine the number of regen plots to establish, using per cent stocking as the variable employed:

"The total number of plots required to sample any given area can be calculated using the formula:

$$N = N \frac{p \times q}{E^2}$$

Where:

N is the total number of plots possible (sampling without replacement).

*p* is the proportion of stocked plots expressed as a decimal.

*q* is 1-*p*; proportion of unstocked plots expressed as a decimal.

E is allowable sampling error, ± 15%, ±10% or so - expressed as a decimal."

Thus, with an E=15%, the number of inner plots = 1991.

Thus, with an E=10%, the number of inner plots = 4480.

Further, when using both inner and outer plots combined, n = 52, where E=15%.

There are three considerations, then, to be addressed when determining the size of the sample population: one is plot size, a second is the frequency and distribution of the attribute data to be used as the basis for sampling intensity, while the third is the proposed level of allowable sampling error.

In passing, it should be noted that the original sampling error per cent based on basal area/ha was also calculated using density of stocking. The result was almost identical in terms of coefficient of variation (104%) and sampling error of  $\pm 4.6\%$ , 19/20 times.

#### **4.2 GROUND VEGETATION:**

Much of the effort expended in the survey was directed at cataloguing the frequency and identity of the ground vegetation present. Observation indicated that most vegetative species were present regardless of disturbance conditions. For instance *Cornus* was present at most plots. Possibly, vegetation should be ignored unless a species not normally present is found. In other words, only unanticipated flora should be recorded, or flora that compete directly with forest renewal.

#### **4.3 SOILS:**

Although the Saskatchewan forest inventory soils classification was easy to apply, future consideration should be given to classifying soil texture and drainage using the Saskatchewan Ecosite Classification Guide recently issued. This does mean that much more field time per polygon will be needed. Probably, a three person crew will be required to maintain the same level of production.

#### **4.4 STUDY CONDUCT:**

A study of this kind, with a large array of field data to gather and with no tested sampling methodology, requires an initial pilot stage for the confirmation of methodology, data entry structures, and skill development without the pressure of logistical shortcomings and time constraints. Preferably, the project could have been managed "in house". This would have removed some of the constraints such as unavailability of the information bases needed for project planning until late into the start up phase. Also, it would have been beneficial to have the opportunity to undertake some analysis on a smaller data set to confirm that all relevant queries could be included.

Further, in the absence of attribute data that identified fire disturbed sites within the 25-year span covered in the productivity study, it was not possible to follow through with that component. However, this may well be possible as an addendum to the study in the future.

Lastly, it would have improved the conduct of the study by having a field survey procedures manual on hand for each crew during the field phase. The opportunity to participate in a pilot operation beforehand would have enabled the client (PAMF) to participate more comfortably in the outcomes induced.

## 5. CONCLUSIONS AND RECOMMENDATIONS

### 5.1 CONCLUSIONS

The following conclusions cover the major items to be considered in assessing the outcomes of this forest productivity study. They are listed here to assist in the evaluation of the outcomes presented.

#### 5.1.1 Study format and methodology:

The need for a pilot project is beneficial when a study of this nature is initiated. For one thing, it has an unavoidable research component attached to it because this level of forest management investigation is not yet a routine procedure such as a timber cruise or forest regeneration survey in which the methodology has already been documented in an approved manual. Also, outcomes from the analyses of data would better prepare the client, perhaps also result in changes in terms of references, such that a more defined set of priorities is established beforehand.

The sampling methodology was limited by the budget available. Consequently, the results attached to the 20,000 ha of clearcut logging, sampled were accurate at the forest level, but are probably in error for any particular polygon or species grouping. Also, average basal area per ha, as a measure used to test the achievement of the sampling objective, combines stand density and degree of stocking, which are the major attributes controlling forest productivity at the juvenile stages.

The high CVs' encountered do not lessen the value of forest level results. In fact, sampling errors at the strata level were lower than  $\pm 10$  percent, 19 times out of 20.

#### 5.1.2 Conclusions regarding productivity:

At the forest level sampled, it was concluded that:

- i) Over time, the difference in productivity between planted clearcuts and those which were naturally regenerated may shrink. In these early years, planting does improve productivity, in mean basal area terms, by 107 % in cutovers younger than 15 year; however, by age 22 years the incremental basal area has increased 3.9 times the initial value.
- ii) In natural stands less than 10 years old, the average basal area is interpolated to be 4.8 m<sup>2</sup>/ha; but at 31 years basal area has increased by 2.4 times.
- iii) In terms of diameter, regeneration less than 15 years is 49% larger in plantations than in naturally reforested stands; however, at 31 years this tendency is reduced - the differential is only 4.6 %;
- iv) The effects of spacing and cleaning within plantations has not been accounted for in the comparisons made here; possibly, the high CV (121%) encountered in the 8P stratum was due to some cleaning and spacing;

- v) Planting achieved a basal area threshold value of 11.5 m<sup>2</sup>/ha 9 years faster than natural regeneration (29% sooner).

From derived data it was concluded that:

- vi) SDI is a useful measure for comparing productivity in stands of different ages and history; admittedly, this tool was developed for application to mature stands. It is also concluded that more research in the development of SDI curves for application to juvenile growing stock is desirable. Again, it is seen that SDI confirms that planted stands have the edge over naturally regenerated stands after age 20.
- vii) Site index (SI) is not a useful measure for comparing productivity in juvenile stands because of the large variation in height and age within stands that are still developing.
- viii) Incremental basal area growth and 3-year height growth are too variable to provide adequate comparisons between stands.
- ix) It is possible to set productivity standards based on numbers of trees per ha and diameter of the tree of average basal area. These are the potential crop trees and this information could be used, for instance, to determine which regenerated stands are sufficiently advanced so that adjacent mature timber could be scheduled for harvest.
- x) Natural stands in the older age classes are in most danger of loss from fire due to the presence of large piles of partially decomposed slash and debris. This reflects the utilization and silvicultural practices of that era.

It is also concluded that a study is needed to generate SDI measures for stands that were fire-disturbed, in order to confirm management benchmarks for developing stands.

## **5.2 RECOMMENDATIONS**

- a) A study of selected stand types generated from fire should be initiated.
- b) Further refinement of SDI applications to juvenile stands should be initiated; probably through a co-operative research effort with industry. The results will assist with the development of monitoring and auditing of performance of forest managers over time.
- c) Only ground vegetation that is exceptional should be recorded; no further recording of basal area increment or 3-year height growth is necessary for stands within the age groups sampled.
- d) From this study, a modified sampling system should be developed and tested, together with instructions for field survey and data collection. Also, a defined data entry structure and analytical format - all to become part of a manual which should be reviewed by a focus group prior to adoption.

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**APPENDIX 1**  
**SAMPLING DISTRIBUTION**

**APPENDIX 2**  
**TALLYSHEET**

## **APPENDIX 3**

### **DISTURBED LANDS DATABASE STRUCTURE - FIELD DATA ENTRY**

## **APPENDIX 4**

### **DISTURBED LANDS DATABASE STRUCTURE - ANALYSIS**

## **APPENDIX 5**

### **SUMMARY OF STAND DENSITY INDEX VALUES, BA AND SI-50 ESTIMATES BY STRATA AND SAMPLE SPECIES**





MEAN STAND DENSITY INDEX ESTIMATES SUMMARIZED BY STRATA

Planted: 1981-1990

SDI BY SPECIES	ALL SPECIES	Aspen	Balsam Poplar	White Birch	Jack Pine	White Spruce	Black Spruce	Balsam Fir	Larch
Soil Texture									
COARSE									
Mean	1356	373	46	19	811	86	15	1	
7 Std Err of Mean	86	60	13	6	71	12	15	1	
2 Valid Plots	172	172	172	172	172	172	172	172	172
172 FINE									
Mean	1355	610	16	36	626	65	0	0	
1 Std Err of Mean	94	81	10	11	79	12	0	0	
1 Valid Plots	140	140	140	140	140	140	140	140	140
140 VERY FINE									
Mean	1201	335	24	43	690	108	0	0	
0 Std Err of Mean	128	68	13	18	94	30	0	0	
0 Valid Plots	85	85	85	85	85	85	85	85	85
85 Total									
Mean	1323	448	31	30	720	83	7	0	
3 Std Err of Mean	57	42	7	6	46	9	7	0	
1 Valid Plots	397	397	397	397	397	397	397	397	397
397									





MEAN SITE INDEX-50 ESTIMATES SUMMARIZED BY STRATA

Natural 1961-1980

	SAMPLE TREE SPECIES		
	JP	TA	WS
	SI-50	SI-50	SI-50
Soil Texture			
Coarse			
Mean Site Index - 50	15.43	16.21	11.10
Std Err of Mean	.74	1.14	.
Valid Plots	15	21	1
Fine			
Mean Site Index - 50	12.79	13.43	11.49
Std Err of Mean	.70	.39	1.00
Valid Plots	33	81	16
Very Fine			
Mean Site Index - 50	12.36	16.18	16.66
Std Err of Mean	1.74	.94	3.61
Valid Plots	6	8	3
All Sites			
Mean Site Index - 50	13.48	14.16	12.24
Std Err of Mean	.53	.38	1.01
Valid Plots	54	110	20

Planted 1961-1980

	SAMPLE TREE SPECIES		
	JP	TA	WS
	SI-50	SI-50	SI-50
Soil Texture			
Coarse			
Mean Site Index - 50	12.73	17.18	18.92
Std Err of Mean	.68	1.02	1.55
Valid Plots	18	13	4
Fine			
Mean Site Index - 50	13.37	13.99	9.66
Std Err of Mean	.74	.50	.
Valid Plots	25	49	1
Very Fine			
Mean Site Index - 50	12.50	13.30	6.53
Std Err of Mean	.50	1.28	.
Valid Plots	2	9	1
All Sites			
Mean Site Index - 50	13.07	14.49	15.31
Std Err of Mean	.49	.44	2.52
Valid Plots	45	71	6

MEAN SITE INDEX-50 ESTIMATES SUMMARIZED BY STRATA

Natural 1981-1990

	SAMPLE TREE SPECIES		
	JP	TA	WS
	SI-50	SI-50	SI-50
Soil Texture			
Coarse			
Mean Site Index - 50	14.07	15.00	.
Std Err of Mean	.79	.96	.
Valid Plots	27	15	0
Fine			
Mean Site Index - 50	13.48	14.74	16.12
Std Err of Mean	.66	.48	.
Valid Plots	30	64	1
Very Fine			
Mean Site Index - 50	13.03	14.70	.
Std Err of Mean	1.68	.69	.
Valid Plots	6	26	0
All Sites			
Mean Site Index - 50	13.69	14.77	16.12
Std Err of Mean	.48	.36	.
Valid Plots	63	105	1

Planted 1981-1990

	SAMPLE TREE SPECIES		
	JP	TA	WS
	SI-50	SI-50	SI-50
Soil Texture			
Coarse			
Mean Site Index - 50	15.29	14.37	14.18
Std Err of Mean	.58	1.03	1.94
Valid Plots	32	9	4
Fine			
Mean Site Index - 50	14.13	13.97	11.70
Std Err of Mean	.85	.82	1.54
Valid Plots	28	17	3
Very Fine			
Mean Site Index - 50	12.77	12.00	13.84
Std Err of Mean	1.03	1.28	.
Valid Plots	18	4	1
All Sites			
Mean Site Index - 50	14.29	13.83	13.21
Std Err of Mean	.46	.58	1.12
Valid Plots	78	30	8

**APPENDIX 6**

**SUMMARY OF ANALYSIS OF VARIANCE RESULTS**

\*\*\* ANALYSIS OF VARIANCE \*\*\*

by SDI10  
CDECADE  
CTYPE  
CTEXT

EXPERIMENTAL sums of squares  
Covariates entered FIRST

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	672525022	4	168131255.411	149.934	.00
CDECADE	543374307	1	543374307.002	484.565	.000
CTYPE	49619936	1	49619935.687	44.250	.000
CTEXT	16337728	2	8168863.995	7.285	.001
2-Way Interactions	31378117	5	6275623.345	5.596	.000
CDECADE CTYPE	29509223	1	29509223.101	26.315	.000
CDECADE CTEXT	631292	2	315645.987	.281	.755
CTYPE CTEXT	2155611	2	1077805.378	.961	.383
3-Way Interactions	13723778	2	6861888.913	6.119	.002
CDECADE CTYPE CTEXT	13723778	2	6861888.913	6.119	.002
Explained	717626916	11	65238810.563	58.178	.00
Residual	2178814311	1943	1121366.089		
Total	2896441227	1954	1482313.832		

2159 cases were processed.  
204 cases (9.4 pct) were missing.

\*\*\* ANALYSIS OF VARIANCE \*\*\*

by SDI10  
CDECADE  
CTYPE  
CDRAIN

EXPERIMENTAL sums of squares  
Covariates entered FIRST

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	691126831	5	138225366.208	124.638	.00
CDECADE	558856967	1	558856966.718	503.921	.000
CTYPE	40324299	1	40324299.280	36.360	.000
CDRAIN	34939537	3	11646512.463	10.502	.000
2-Way Interactions	42715755	7	6102250.738	5.502	.000
CDECADE CTYPE	25859132	1	25859132.406	23.317	.000
CDECADE CDRAIN	12946493	3	4315497.607	3.891	.009
CTYPE CDRAIN	2332731	3	777577.083	.701	.551
3-Way Interactions	12213203	3	4071067.541	3.671	.012
CDECADE CTYPE CDRAIN	12213203	3	4071067.541	3.671	.012
Explained	746055789	15	49737052.589	44.848	.00
Residual	2150385438	1939	1109017.761		
Total	2896441227	1954	1482313.832		

2159 cases were processed.  
204 cases (9.4 pct) were missing.

\*\*\* ANALYSIS OF VARIANCE \*\*\*

by SDI10  
CDECADE  
CTYPE  
NORG

EXPERIMENTAL sums of squares  
Covariates entered FIRST

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	666002342	4	166500585.485	147.513	.00
CDECADE	562713149	1	562713148.964	498.541	.000
CTYPE	45590643	1	45590643.363	40.391	.000
NORG	9815048	2	4907524.143	4.348	.013
2-Way Interactions	32483510	5	6496702.050	5.756	.000
CDECADE CTYPE	26312292	1	26312292.126	23.312	.000
CDECADE NORG	2106674	2	1053337.058	.933	.393
CTYPE NORG	378874	2	189437.038	.168	.846
3-Way Interactions	4854736	2	2427368.031	2.151	.117
CDECADE CTYPE NORG	4854736	2	2427368.031	2.151	.117
Explained	703340588	11	63940053.477	56.648	.00
Residual	2193100639	1943	1128718.805		
Total	2896441227	1954	1482313.832		

2159 cases were processed.  
204 cases (9.4 pct) were missing.

\*\*\* ANALYSIS OF VARIANCE \*\*\*

by SDI10  
CDECADE  
CTYPE  
COMP\_CLA

EXPERIMENTAL sums of squares  
Covariates entered FIRST

Source of Variation	Sum of Squares	DF	Mean Square	F	Sig of F
Main Effects	627347114	5	125469422.848	114.505	.00
CDECADE	539894822	1	539894822.008	492.714	.000
CTYPE	42840926	1	42840925.981	39.097	.000
COMP_CLA	8784178	3	2928059.299	2.672	.046
2-Way Interactions	45354882	7	6479268.877	5.913	.000
CDECADE CTYPE	22083728	1	22083728.390	20.154	.000
CDECADE COMP_CLA	17731938	3	5910646.038	5.394	.001
CTYPE COMP_CLA	1917011	3	639003.533	.583	.626
3-Way Interactions	9138496	3	3046165.332	2.780	.040
CDECADE CTYPE COMP_CLA	9138496	3	3046165.332	2.780	.040
Explained	681840492	15	45456032.825	41.484	.00
Residual	2021671143	1845	1095756.717		
Total	2703511635	1860	1453500.879		

2159 cases were processed.  
298 cases (13.8 pct) were missing.

\*\*\*\*\* Analysis of Variance -- Design 1 \*\*\*\*\*

Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	7956.06	573	13.88		
CDECADE	135.72	1	135.72	9.77	.002
CTYPE	17	1	17	.59	.443
CTEXT	252.57	2	126.29	9.10	.000
CDRAIN	125.36	3	42.12	3.03	.029
NORG	21.80	2	10.90	1.11	.331
COMP_CLA	33.37	3	11.12	.95	.418
N1SAMPLE	555.45	5	111.09	8.45	.000
CDECADE * N1SAMPLE	14.97	4	3.74	.27	.898
CTYPE * N1SAMPLE	38.10	4	9.52	.69	.602
CTEXT * N1SAMPLE	211.50	8	25.19	1.81	.072
CDRAIN * N1SAMPLE	66.30	9	7.37	.53	.853
N1SAMPLE * NORG	21.32	7	3.05	.63	.730
COMP_CLA * N1SAMPLE	255.02	12	21.25	1.59	.090
(Model)	1825.64	61	29.93	2.16	.000
(Total)	9762.70	634	15.43		

R-Squared = .187

Adjusted R-Squared = .100

\*\*\*\*\* Analysis of Variance -- Design 1 \*\*\*\*\*

Source of Variation	SS	DF	SEQUENTIAL MS	Sums of Squares F	Squares Sig of F
WITHIN+RESIDUAL	66746.14	226	295.34		
CDECADE	1894.69	1	1894.69	6.42	.012
CTYPE	2437.80	1	2437.80	8.25	.004
CTEXT	13920.92	2	6960.46	23.57	.000
CDRAIN	3020.79	3	1006.93	3.41	.018
NORG	1047.31	2	523.65	1.77	.172
COMP_CLA	3297.45	3	1099.15	3.72	.012
NISAMPLE	9633.86	5	1926.77	6.52	.000
CDECADE * NISAMPLE	2365.57	3	788.52	2.67	.048
CTYPE * NISAMPLE	1101.62	4	275.41	.93	.446
CTEXT * NISAMPLE	1684.29	6	280.71	.95	.460
CDRAIN * NISAMPLE	8552.28	7	1221.75	4.14	.000
NISAMPLE * NORG	2199.52	7	314.22	1.06	.388
COMP_CLA * NISAMPLE	3815.14	10	381.51	1.29	.236
(Model)	54971.25	54	1017.99	3.45	.000
(Total)	121717.38	280	434.70		

R-Squared = .452  
Adjusted R-Squared = .321

\*\*\*\*\* Analysis of Variance -- Design 1 \*\*\*\*\*

Tests of Significance for SIHT3 using SEQUENTIAL Sums of Squares					
Source of Variation	SS	DF	MS	F	Sig of F
WITHIN+RESIDUAL	83.29	743	.11		
CDECADE	.87	1	.87	7.72	.006
CTYPE	4.49	1	4.49	40.05	.000
CTEXT	10.75	2	5.37	47.93	.000
CDRAIN	2.78	3	.93	8.26	.000
NORG	.95	2	.48	4.26	.015
COMP_CLA	1.78	3	.59	5.28	.001
NISAMPLE	4.25	5	.85	7.58	.000
CDECADE * NISAMPLE	3.62	4	.91	8.08	.000
CTYPE * NISAMPLE	1.57	4	.39	3.50	.008
CTEXT * NISAMPLE	6.88	8	.86	7.67	.000
CDRAIN * NISAMPLE	.87	10	.09	.77	.654
NISAMPLE * NORG	.76	7	.11	.97	.453
COMP_CLA * NISAMPLE	1.72	11	.16	1.40	.170
(Model)	41.28	61	.68	6.04	.000
(Total)	124.57	804	.15		
R-Squared =	.331				
Adjusted R-Squared =	.276				

-----

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-@-10cm)  
By Variable CDECADE PERIOD OF DISTURBANCE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	601668843.2	601668843.2	512.0592	.0000
Within Groups	1953	2294772384	1174998.660		
Total	1954	2896441227			

No range tests performed with fewer than three non-empty groups.

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-@-10cm)  
By Variable CTYPE TYPE OF TREATMENT

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	83537795.02	83537795.02	58.0003	.0000
Within Groups	1953	2812903432	1440298.736		
Total	1954	2896441227			

No range tests performed with fewer than three non-empty groups.

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-@-10cm)  
By Variable CTEXT Soil Texture

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	1013508.845	1013508.845	.6777	.4105
Within Groups	1615	2415213323	1495488.126		
Total	1616	2416226832			

No range tests performed with fewer than three non-empty groups.

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-@-10cm)  
By Variable CDRAIN SOIL DRAINAGE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	70610541.15	23536847.05	16.2502	.0000
Within Groups	1951	2825830686	1448401.172		
Total	1954	2896441227			

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-@-10cm)  
By Variable CDRAIN SOIL DRAINAGE

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 850.9998 * RANGE * \sqrt{(1/N(I) + 1/N(J))}$   
 with the following value(s) for RANGE: 3.65

(\*) Indicates significant differences which are shown in the lower triangle

Mean	CDRAIN	
805.9800	Grp 4	G G G G
1173.4599	Grp 1	r r r r
1337.7411	Grp 3	p p p p
1563.8720	Grp 2	4 1 3 2
		* *

y                    - - - - - O N E W A Y - - - - -

Variable SDI10        SDI (t/ha-0-10cm)  
By Variable NORG        ORGANIC DEPTH

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	12501325.81	6250662.904	4.2308	.0147
Within Groups	1952	2883939901	1477428.228		
Total	1954	2896441227			

- - - - - O N E W A Y - - - - -

Variable SDI10        SDI (t/ha-0-10cm)  
By Variable NORG        ORGANIC DEPTH

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 859.4848 * RANGE * \sqrt{(1/N(I) + 1/N(J))}$   
 with the following value(s) for RANGE: 3.33

(\*) Indicates significant differences which are shown in the lower triangle

Mean	NORG	
1351.3468	Grp 2	
1379.3927	Grp 1	
1775.1497	Grp 3	* *

G G G  
r r r  
p p p  
2 1 3

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-0-10cm)  
By Variable COMP\_CLA COMPETITION CLASS

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	6652982.755	2217660.918	1.5270	.2056
Within Groups	1857	2696858652	1452266.372		
Total	1860	2703511635			

- - - - - O N E W A Y - - - - -

Variable SDI10 SDI (t/ha-0-10cm)  
By Variable COMP\_CLA COMPETITION CLASS

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 852.1345 * RANGE * \sqrt{(1/N(I) + 1/N(J))}$   
 with the following value(s) for RANGE: 3.65

- No two groups are significantly different at the .050 level

NS1: 1 JP

- - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable CDECADE PERIOD OF DISTURBANCE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	31.0204	31.0204	2.1259	.1461
Within Groups	238	3472.7353	14.5913		
Total	239	3503.7556			

No range tests performed with fewer than three non-empty groups.

NS1: 2 TA

- - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable CDECADE PERIOD OF DISTURBANCE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	5.6478	5.6478	.3959	.5297
Within Groups	314	4479.4787	14.2659		
Total	315	4485.1265			

No range tests performed with fewer than three non-empty groups.

NS1: 3 WS

- - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable CDECADE PERIOD OF DISTURBANCE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	2.2372	2.2372	.1054	.7475
Within Groups	33	700.2403	21.2194		
Total	34	702.4775			

No range tests performed with fewer than three non-empty groups.

NS1: 1 JP

----- O N E W A Y -----

Variable SI Site Index  
By Variable CTYPE TYPE OF TREATMENT

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	3.9248	3.9248	.2669	.6059
Within Groups	238	3499.8308	14.7052		
Total	239	3503.7556			

No range tests performed with fewer than three non-empty groups.

NS1: 2 TA

----- O N E W A Y -----

Variable SI Site Index  
By Variable CTYPE TYPE OF TREATMENT

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	1.8403	1.8403	.1289	.7198
Within Groups	314	4483.2862	14.2780		
Total	315	4485.1265			

No range tests performed with fewer than three non-empty groups.

NS1: 3 WS

----- O N E W A Y -----

Variable SI Site Index  
By Variable CTYPE TYPE OF TREATMENT

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	23.6880	23.6880	1.1516	.2910
Within Groups	33	678.7895	20.5694		
Total	34	702.4775			

No range tests performed with fewer than three non-empty groups.

NS1: 1 JP

----- ONEWAY -----

Variable SI Site Index  
By Variable CTEXT Soil Texture

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	91.4609	45.7304	3.1762	.0435
Within Groups	237	3412.2948	14.3979		
Total	239	3503.7556			

NS1: 1 JP

----- ONEWAY -----

Variable SI Site Index  
By Variable CTEXT Soil Texture

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.6831 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.34

- No two groups are significantly different at the .050 level

NS1: 2 TA

----- ONEWAY -----

Variable SI Site Index  
By Variable CTEXT Soil Texture

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	151.7811	75.8905	5.4816	.0046
Within Groups	313	4333.3454	13.8446		
Total	315	4485.1265			

NS1: 2 TA

----- ONEWAY -----

Variable SI Site Index  
By Variable CTEXT Soil Texture

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.6310 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.34

(\*) Indicates significant differences which are shown in the lower triangle

Mean	CTEXT	
14.0027	Grp 2	
14.4538	Grp 3	
15.8284	Grp 1	*

G G G  
r r r  
p p p  
2 3 1

NS1: 3 WS

----- ONEWAY -----

Variable SI  
By Variable CTEXT

Site Index  
Soil Texture

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	121.4367	60.7183	3.3440	.0480
Within Groups	32	581.0408	18.1575		
Total	34	702.4775			

NS1: 3 WS

----- ONEWAY -----

Variable SI  
By Variable CTEXT

Site Index  
Soil Texture

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 3.0131 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.47

(\*) Indicates significant differences which are shown in the lower triangle

Mean	CTEXT	
11.6514	Grp 2	
14.0720	Grp 3	
15.9411	Grp 1	*

G G G  
r r r  
p p p  
2 3 1

NS1: 1 JP

----- ONEWAY -----

Variable SI  
By Variable CDRAIN

Site Index  
SOIL DRAINAGE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	53.7565	17.9188	1.2258	.3010
Within Groups	236	3449.9992	14.6186		
Total	239	3503.7556			

NS1: 1 JP

----- ONEWAY -----

Variable SI  
By Variable CDRAIN

Site Index  
SOIL DRAINAGE

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.7036 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.66

- No two groups are significantly different at the .050 level

NS1: 2 TA

----- O N E W A Y -----

Variable SI Site Index  
By Variable CDRAIN SOIL DRAINAGE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	31.6075	10.5358	.7381	.5300
Within Groups	312	4453.5190	14.2741		
Total	315	4485.1265			

NS1: 2 TA

----- O N E W A Y -----

Variable SI Site Index  
By Variable CDRAIN SOIL DRAINAGE

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.6715 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.66

- No two groups are significantly different at the .050 level

NS1: 3 WS

----- O N E W A Y -----

Variable SI Site Index  
By Variable CDRAIN SOIL DRAINAGE

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	2	30.4749	15.2374	.7256	.4918
Within Groups	32	672.0026	21.0001		
Total	34	702.4775			

NS1: 3 WS

----- O N E W A Y -----

Variable SI Site Index  
By Variable CDRAIN SOIL DRAINAGE

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 3.2404 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.47

- No two groups are significantly different at the .050 level

NS1: 1 JP

----- O N E W A Y -----

Variable SI Site Index  
By Variable NORG ORGANIC DEPTH

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	1	6.5649	6.5649	.4468	.5045
Within Groups	238	3497.1907	14.6941		
Total	239	3503.7556			

No range tests performed with fewer than three non-empty groups.

NS1: 2 TA - - - - - O N E W A Y - - - - -

Variable	SI	Site Index	Analysis of Variance					
By Variable	NORG	ORGANIC DEPTH	Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
			Between Groups	2	97.8326	48.9163	3.4898	.0317
			Within Groups	313	4387.2939	14.0169		
			Total	315	4485.1265			

NS1: 2 TA - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable NORG ORGANIC DEPTH  
Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.6473 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
 with the following value(s) for RANGE: 3.34

(\*) Indicates significant differences which are shown in the lower triangle

Mean	NORG	Grp	Significance
13.8041	Grp 2		
14.5556	Grp 1		
16.7164	Grp 3		*

NS1: 3 WS - - - - - O N E W A Y - - - - -

Variable	SI	Site Index	Analysis of Variance					
By Variable	NORG	ORGANIC DEPTH	Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
			Between Groups	2	40.9863	20.4931	.9914	.3822
			Within Groups	32	561.4912	20.6716		
			Total	34	732.4775			

NS1: 3 WS - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable NORG ORGANIC DEPTH  
Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 3.2149 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
 with the following value(s) for RANGE: 3.47

- No two groups are significantly different at the .050 level

NS1: 1 JP - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable COMP\_CLA COMPETITION CLASS

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	22.9094	7.6365	.5142	.6729
Within Groups	221	3281.8505	14.8500		
Total	224	3304.7599			

NS1: 1 JP - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable COMP\_CLA COMPETITION CLASS

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.7249 * RANGE * \sqrt{(1/N(I) + 1/N(J))}$   
with the following value(s) for RANGE: 3.67

- No two groups are significantly different at the .050 level

NS1: 2 TA - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable COMP\_CLA COMPETITION CLASS

Analysis of Variance

Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	26.2398	8.7466	.6118	.6078
Within Groups	302	4317.7248	14.2971		
Total	305	4343.9646			

NS1: 2 TA - - - - - O N E W A Y - - - - -

Variable SI Site Index  
By Variable COMP\_CLA COMPETITION CLASS

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.6737 * RANGE * \sqrt{(1/N(I) + 1/N(J))}$   
with the following value(s) for RANGE: 3.66

- No two groups are significantly different at the .050 level

NS1: 3 WS

----- O N E W A Y -----

Variable By Variable	SI COMP_CLA	Site Index COMPETITION CLASS	Analysis of Variance		
Source	D.F.	Sum of Squares	Mean Squares	F Ratio	F Prob.
Between Groups	3	144.2282	48.0761	2.6833	.0651
Within Groups	29	519.5810	17.9166		
Total	32	663.8092			

NS1: 3 WS

----- O N E W A Y -----

Variable SI Site Index  
By Variable COMP\_CLA COMPETITION CLASS

Multiple Range Tests: Tukey-HSD test with significance level .050

The difference between two means is significant if  
 $MEAN(J) - MEAN(I) \geq 2.9930 * RANGE * \sqrt{1/N(I) + 1/N(J)}$   
with the following value(s) for RANGE: 3.85

- No two groups are significantly different at the .050 level