VALIDATION OF MIXED WOOD COMPETITION THRESHOLDS FOR THE DEVELOPMENT OF FREE-TO-GROW SURVEY PROCEDURES IN MANITOBA

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ABSTRACT

In 1994, a study was undertaken to determine the validity of Free-to-Grow thresholds developed for mixed juvenile stands in Manitoba. A total of 1902 40 m^2 plots in 91 blocks were surveyed throughout Manitoba. Measurements were made of representative conifers designated as Free-to-Grow and not-Free-to-Grow, using the relative height and distance standards based on earlier work by MacIsaac. Tree ring analysis indicated that there was no significant age bias in the field aging of FTG trees compared to not-FTG trees, based on internode counts. Height and root collar diameter of 10-14 year old Free-to-Grow trees, was significantly larger than the not Free-to-Grow trees for all conifer species, except for black spruce height. This affirms the use of the hardwood competitor distance and height thresholds as defined for the Free-To-Grow survey protocol used in this study, for the species and sites sampled. In many blocks, maximum conifer growth on the block and the best average growth was associated with a low to moderate level of aspen competition. While some aspen retention may be beneficial in the initial regeneration phase, some of the hardwood competition may have to be removed later on, to reduce the negative effects on conifer growth from overtopping hardwoods.

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1.0 INTRODUCTION

From 1991-1993, a comprehensive study was undertaken to test the competition dynamics of mixed regeneration competition in Manitoba. The results are reported in MacIsaac (1995). This report summarizes the analysis made on data collected in 1994 to determine the effectiveness of the distance and height thresholds which were suggested based on the 1991-93 data collection.

The overall objectives of this report were to test the following questions:

1. Are the hardwood-conifer distance thresholds based on the 1991-1993 study appropriate? In other words, is the limiting distance threshold appropriate?
2. Are the relative hardwood-conifer height thresholds based on the 1991-1993 study appropriate? In other words, is the relative height threshold appropriate?

2.0 FIELD METHODS

The sampling objective was to operationally test the Free-to-Grow (FTG) protocol being developed by the Manitoba Forestry Branch, based on the height and distance thresholds derived from work done in 1991-1993. There was also a requirement to collect additional information to verify the major results.

An initial free-to-grow protocol was developed based on results of analysis of the 1991-1993 data, and field testing on June 15 1994 in the Agassiz Region (one black spruce and one white spruce block) by Jeff Delaney (Manitoba Forestry Branch) and Dan MacIsaac (Canadian Forest Service). The final protocol used throughout the 1994 summer survey followed two days of testing by the field crews in the Porcupine Hills, July 5-6, with modification by Jeff Delaney and Dan MacIsaac.

2.1 Block Selection

Blocks were selected based on review of regeneration records in the Manitoba Forestry Branch. There were three criteria for initial block selection:

a) Minimum 55% conifer stocking for all species combined.
b) Hardwood competition ranging from 30-100% hardwood stocking.
c) Blocks older than 9 years after harvest.

The office review generated a potential list of 108 blocks covering 3,727 ha, from around the province, most around 12 years old. By the end of the 1994 field season, 91 blocks from five forest areas had been surveyed (Table 1).

2.2 Plot Layout

In order to obtain data from a wide range of blocks, a sampling intensity of 0.5 plots per ha was used. The plot layout followed an irregular pattern which conformed to the block shape. The pattern of plot

Table 1
Number of Blocks and Plots Surveyed by Area

Area	Blocks	Plots[1]	Major Conifers
Pine Falls	22	399	JP, BS
Eastern	7	60	JP, BS
Central	3	50	JP
Western	26	556	JP, WS, BS
Northwest	33	837	JP, BS
Total	91	1902	

1. Plots are 40 m^2, not conifer-tree centred.

location was in some blocks, a "W" pattern, and in other blocks, several "L's". Plots were spaced out 100 m apart along these lines. The number of plots ranged from 2 to 69 per block.

The plots were 40 m^2 in area (3.56 m radius). British Columbia uses a 50 m^2 plot for their Free Growing surveys. The smaller plot was used in this study because larger plots would be difficult to survey in dense regeneration areas.

The following variables were recorded in the office prior to the survey (recorded once per block): Date of data collection, Original cover type, Block size, Harvest (Depletion) - type and year, Site preparation - type and year, Planting - stock type and year and Stand Tending - type and year.

In addition, a number of block level site variables were assessed by the crew chief in the field as follows: Aspect, Slope (%), Slope position, Drainage class, Moisture class and Site quality. Simplified site assessment classes comprising two to five classes for each variable were used (e.g., Drainage classes: well, poor; Moisture Classes: dry, fresh, moist, wet). Simple classifications were adopted because using more complex site variable classifications would be more time consuming to learn and apply consistently and the information was secondary in importance.

2.3 Operational Free-to-Grow Survey Measurements

Measurements were made to represent the operational aspects of a FTG survey and included stem density counts, based on a set of height/spacing criteria. Adopting a methodology used in British Columbia, three independent assessments were made in each plot: a stocking density survey, a well-spaced density survey and a free-to-grow survey (Appendix 1).

1. The Following Guidelines were followed for each survey.

a) Total stocking by individual species (hardwood and conifer). The minimum heights for counting in the stocking tally was 0.2 m for conifers and 1.0 m for hardwoods.

b) Number of well-spaced trees by individual species (hardwood and conifer). In order to be counted as well-spaced, the following minimum heights were used: Black Spruce-0.5m, White Spruce-0.5m, Jack Pine-1.5m, Other Conifers-1.0m, Hardwoods-1.0m. Well spaced conifers had to be at least 1.5 m from other well spaced conifers. Well spaced hardwoods had to be at least 2.0 m from other well spaced hardwoods.

c) Number of FTG conifer trees species by acceptable commercial species. In order to be counted as FTG, the following minimum heights and intertree distances were used:
Minimum Height: Black Spruce-0.5m, White Spruce-0.5m, Jack Pine-1.5m, Other Conifers-1.0m
Distance to Hardwood Competitor Greater than ⅔ the height of the target tree:
Black Spruce-1.0m, White Spruce-1.0m, Jack Pine-1.25m, Other Conifers-1.0m

Density information for the three surveys included counting all trees except trees smaller than 20 cm for conifers and 100 cm for aspen. If there was a significant number of smaller trees, this was recorded in the comments section.

For all three surveys, the average height was measured every fifth plot. This was not based on arithmetic means, but the height of the average canopy. This meant that the larger trees were given more weight. The fifth plot measurements were deemed to be sufficient to represent the general height conditions in the block.

In addition, a plot location map was produced. This was required for stratifying the block into subblocks if needed, and to tie FTG survey results with regeneration maps.

2.4 Additional Data Required to Assess the Free-to-Grow Survey Method

There were two components that had to be measured in order to determine the efficacy of the height and distance thresholds used in the prototype FTG survey. These were: 1. A measure of hardwood and shrubby competition and 2. A measurement of performance of trees designated as FTG *versus* not-FTG. This required additional information above the operational FTG survey information.

1. <u>Hardwood and Shrub Competition</u>

The 1991-93 data collection was on a subset of the existing site conditions, where hardwoods were the major competitor. For this validation study, it was important to collect basic information on competitor dominance and site conditions, especially if the site was outside the range of competition types and site conditions already sampled in 1991-1993. For example, the analysis on 1991-93 data indicated that shrubs had a negligible effect on the tree growth for stands between 8-12 years old. If the 1994 surveys were done in areas of heavy shrub cover, this needed to be documented, to determine how it affected the FTG survey results.

In each plot, average cover (using a modified six-class Braun-Blanquet cover class system (Mueller-Dombois and Ellenberg 1974)) and average height was recorded for shrubs and hardwoods (estimated separately for each species). Cover estimates were based on the following class scale: 1=< 1%; 2= 1-5% ; 3=5-25%; 4=25-50%; 5=50-70%; 6=75-100%. Up to four of the most important shrubby competitors were measured. Grass and forbs were not measured, because grass competition was not a problem for the blocks sampled. If it was a locally-major competitor, it was noted in the comments section, on the back side of the data form.

2. <u>Performance of Free-to-Grow Trees Compared to Not-Free-to-Grow Trees</u>

In order to determine the growth performance of FTG trees *versus* not-FTG trees, height over age and root collar diameter (RCD) over age curves were developed for each species based on all areas. These could be stratified by site type and species, to determine how effective the standards were. To achieve this, one representative FTG and one representative not-FTG tree in each plot (where a representative tree was a single tree which most closely comes to the average), were measured for the following:

a) height, including current year's growth (m, to nearest 5 cm)
b) RCD at ground level, above any root collar swelling (mm)
c) height increment for current year (cm)
d) height increment for current year (cm)
e) estimate of age based on internodes, taking into account the block age, and planting information as a guide (the lower 40 cm usually did not have well-defined terminal bud scars)

Where there were several commercial species in the plot, the measurements were taken from the dominant commercial species in the plot. At the first plot in the block, and for every fifth plot thereafter, basal tree disks of the representative FTG and not-FTG trees was collected.

Determination of Representative Free-to-Grow and Not-Free-to-Grow Trees

A representative FTG tree was subjectively selected from the tallied FTG trees. This representative FTG tree met the FTG tree criteria: healthy, not damaged, well spaced (1.5 m) from other FTG trees, greater than the required minimum height (see section 2.3) and no stems of competing trees or shrubs trees greater than ⅔ the height of the tree, within the specified distance for that species (see section 2.3). In each plot, the representative FTG tree along with a representative not-FTG tree was selected to represent the average tree size in the plot.

Definition of a Free-to-Grow Tree

In a strict sense, a tree was defined as FTG if there were no stems of a competing tree or shrub within the FTG distance, in which the competitor's foliage was taller than ⅔ the height of the target tree. For hardwood competitors this rule was followed strictly, so that a conifer would be deemed as not-FTG even if a small part of the hardwood foliage was within this zone. In the field, some deviation from this rule was allowed for shrubby competitors if a small amount of foliage entered this zone. This was based on a judgement call on how deleterious the growth is to the target tree, presently and in the future. For example, if the competitor's foliage was on the north side of the tree, or if it was a shrub which wouldn't be growing any higher, then the tree may still be deemed as FTG.

3.0 ANALYSIS METHODS

While there were five species measured (black spruce, white spruce, jack pine, balsam fir, tamarack) and blocks were sampled in five areas (Pine Falls, Eastern, Central, Western, Northwest), the majority of data was derived from three species (black spruce, white spruce, jack pine) and three areas (Pine Falls, Western, Northwest) (Table 1 and Appendix 2). Consequently, for analysis stratified by area, only those three areas were used. Likewise, if analysis was stratified by species, only the three most abundant species were used.

Prior to analyses, the statistical properties of each variable were analyzed and tests for normality were performed. The tests for normal distribution were based on a procedure outlined by Sabin and Stafford (1990). In general, square root transformations were applied to the tree growth variables and natural logarithm+1 (to correct for 0 values) were applied to density, cover and height variables. The use of parametric and non-parametric statistics varied depending upon the ability of transformations to achieve normally distributed variates. In cases where it was not clear if the assumptions of population characteristics were valid for parametric tests, then the non-parametric equivalents were used.

3.1 Analysis of Tree Ages

As part of the study, it was important to determine the possible contribution of observer error to the determination of ages of representative FTG and not-FTG trees in the field. A series of paired comparison t-tests were done based on white spruce, black spruce and jack pine, for all the areas combined (to increase the sample size).

Three sets of analyses were performed to answer the following questions:

a) Are the estimated tree ages close to the true ages of the trees?

   The analysis tested if there are significant differences in the age determination, based on the field estimated ages compared to the tree ring-determined ages. In other words, how close the field-estimated ages are to the actual tree-ring-determined ages for FTG and not-FTG trees. The analysis was based on the full set of all trees that had tree-ring-determined ages, and was performed on a species by area basis.

b) Within a plot, were the representative FTG and not-FTG trees the same age?

   The analysis tested how different the true ages based on lab tree ring analysis are between selected FTG and not-FTG trees of the same species from the same plot. The representative FTG and not-FTG trees that were selected in each plot were supposed to be of similar age. If the not-FTG tree was smaller than the FTG tree, the assumption was that this was due to the effects of competition and not due to a younger not-FTG tree age. If this was the case, then it would skew the conclusions of the study, and add credence to the proposed height and distance thresholds used in FTG surveys, when in fact this confidence was not warranted. In other words, the concern was that the difference in size between the FTG and not-FTG trees in each plot were supposed to be due to competition differences, (and the trees were selected to be the same general age), when it was in fact due to an age difference between not-FTG and not-FTG trees (with the latter being younger).The analysis was based on only a subset of tree-ring-determined trees, as derived from cases where there was a tree-ring-determined FTG and not-FTG tree of the same species in the same plot.

c) Is the bias in age estimation greater for FTG trees than for not-FTG trees?

   The analysis tested if the difference in tree-ring-determined age compared to the estimated age is greater for FTG trees than for not-FTG trees, and if this difference is significant. This requires a test for a difference (of FTG *versus* not-FTG tree ages) of a difference (tree-ring-determined compared to field-estimated age). Again, the analysis was based on only a subset of tree-ring-determined trees, as derived from cases where there was a tree-ring-determined FTG and not-FTG tree of the same species in the same plot. This analysis would determine if there was more of a bias in overestimating the age of FTG trees compared to not-FTG trees.

Based on these three tests, differences between tree-ring age and field-estimated age would be used to correct the ages of the trees that were not analysed in the laboratory.

3.2 Growth Differences In Free-To-Grow *Versus* Not-Free-To-Grow Trees

Several approaches were used to determine if there was a statistical difference between FTG and not-FTG tree growth. Initial analysis centred on development of non-linear growth models for FTG not-FTG trees stratified by species and area. The second approach involved the use of paired comparisons tests between FTG and not-FTG trees of the same species. The results of these tests were verified by plots of mean FTG and not-FTG growth response over age for height and RCD.

3.3 Effect of Competition Levels and Site Conditions on Growth of Free-To-Grow Trees

There were several approaches used to quantify the relationship between FTG tree growth and competition level (cover and height) of hardwoods and shrubs. The first approach was based on analyses of block-level means for both tree growth and competition variables. These mean values were then used in multiple regressions to determine the strength of the relationship.

The second approach involved analysis of variance and covariance. For analysis of variance, several linear models were developed, as appropriate for the experimental design (Borders and Shiver 1989; Neter et al. 1989; SAS Institute Inc. 1991). In some models, hardwood competition and FTG tree age were included as covariates, using an approach by Woollons and White (1988).

In this analysis, the following questions were addressed:

1. Is the variation in competition level, and FTG growth response greater within blocks or between blocks within the same area? For analysis of variance and covariance, the models were:
   Competition Level=block+plot+plot(block)+error
   FTG Growth=Competition Level+block+plot+plot(block)+error
   FTG Growth=FTG Tree Age+block+plot+plot(block)+error

2. Do site conditions have an effect on competition level and growth of FTG trees. For analysis of competition variables after treatment, the models were:
   Competition Level= Drainage Class+error
   FTG Growth= Competition Level+Drainage Class+error
   FTG Growth= FTG Tree Age+Drainage Class+error

   Competition Level= Moisture Class+error
   FTG Growth= Competition Level+Moisture Class+error
   FTG Growth= FTG Tree Age+Moisture Class+error

4.0 RESULTS AND DISCUSSION

4.1 Analysis of Tree Ages

The analyses which determined how close the estimated age was to the tree ring-estimated age are summarized in Table 2 and Appendix-3 for each species. The field-estimated age was, in most cases, an underestimate of true age based on tree ring analysis of the basal disk. For five of the six analyses, based on species by FTG class, this difference was significant ($P<0.05$) (Table 2). The age discrepancy was lowest for jack pine (less than a year for FTG and not-FTG tree groups) and generally highest for white spruce.

The results of the analyses which determine if the FTG and not-FTG trees (of the same species within a plot) were the same age are presented in Table 3 for each species. For all three species, the age discrepancy was less than a year between the true ages of measured FTG and not-FTG trees in the same plot. For spruce the age difference was not significant ($P <0.05$), and in fact, for white spruce, the FTG tree was, on average 0.9 years younger than the not-FTG tree in the same plot. For jack pine, the age difference was quite small (0.4 years), but consistent, as shown by a P value of 0.0001. The fact that the species with the smallest age spread was the only one with a significant age difference may be partly related to sample size. For the white and black spruce, there were only 22 and 36 plot, respectively, that were usable for the analysis, while the pine analysis was based on 177 plots.

For the third question which asked if the bias in age determination was greater for FTG than for not-FTG trees, the results are shown in Table 4 for each species. In all cases the difference in estimated ages and true ages was less than 1 year. The age spread between the age difference involving FTG and not-FTG trees was also less than 1 year, and was only significant for jack pine.

This tree-ring age analysis was used to decide whether there should be some age correction to the trees that were not analysed in the laboratory (disks were collected for only about 20% of the trees that were measured in the field). This analysis determined the mean difference between the lab tree-ring age and field-estimated age for FTG and not-FTG trees separately, for each species by all areas combined, and applied this correction to those trees that weren't analysed in the lab. The dispersion of data around the mean value was used to determine if a uniform age correction was appropriate. In all cases, the standard error of the mean was less than one year, and so a uniform age correction was applied. For black spruce, one and two years were added to the field-estimated age, for FTG and not-FTG trees, respectively (Appendix 3). For jack pine, no age correction was required. For white spruce, an age correction of two years was added to the field-estimated age for both FTG and not-FTG groups. These corrected ages were then used for all subsequent analysis.

4.2 Growth Differences in Free-to-Grow *Versus* Not-Free-to-Grow Trees

The approach used to determine whether there were significantly-different growth trajectories for FTG and not-FTG trees over time, was based on using one height and RCD measurement per tree (i.e., the total height and RCD measured in the field). This was used rather than using the radial

Table 2
Comparison of Field-Estimated and Lab-Analysed Ages
for Measured Free-to-Grow and Not-Free-to-Grow Trees

Species	Number of Trees	Estimated Mean Age[1]	True Mean Age[2]	Age Difference (True-Est.)	Prob > |T|[3]
BS - FTG	65	11.9	14.1	2.4	0.0003
BS- NFTG	84	11.3	12.2	0.9	0.0012
JP - FTG	258	10.4	10.4	0.05	0.5449
JP - NFTG	246	9.7	10.0	0.3	0.0012
WS - FTG	47	12.3	13.9	1.7	0.0001
WS- NFTG	56	12.1	14.0	1.8	0.0001

1. Based on internode counts taken in the field.
2. Based on laboratory tree ring analysis of basal disk.
3. P values of less than 0.05 indicate a significant difference in the true *versus* estimated age of the trees, based on a paired comparison t-test for each tree.

Table 3
Comparison of Difference Between the True Ages of Free-to-Grow and Not-Free-to-Grow Trees of the Same Species in the Same Plot

Species	Number of Trees[1]	True Mean Age of Tree[2]		Age Difference (FTG-NFTG)	Prob >|T|[3]
		FTG	NFTG		
Black Spruce	36	12.5	11.7	0.8	0.1655
Jack Pine	177	10.5	10.1	0.4	0.0001
White Spruce	22	13.4	14.8	-0.9	0.1371

1. The number of trees used in this analysis is significantly less than the total number of trees which were measured in 1994, because only plots which had basal disks taken of FTG trees and NFTG trees which were the same species within the plot were used in this analysis.
2. Based on laboratory tree ring analysis of basal disk.
3. P values of less than 0.05 indicate a significant difference in true age of the FTG and NFTG trees of the same species within the same plot, based on a paired comparison t-test.

Table 4
Comparison of Difference Between the Spread Between Estimated and True Ages of Free-to-Grow *Versus* Not-Free-to-Grow Trees of the Same Species in the Same Plot

Species	Number of Trees[1]	Difference Between Estimated[2] and True[3] Tree Ages		Difference in True-Est. Age Spread Between FTG and NFTG Trees	Prob > |T|[4]
		FTG	NFTG		
Black Spruce	36	0.81	-0.06	0.9	0.1771
Jack Pine	177	0.37	0.73	-0.4	0.0002
White Spruce	22	-0.91	-0.14	-0.8	0.0875

1. The number of trees used in this analysis is significantly less than the total number of trees which were measured in 1994, because only plots which had basal disks taken of FTG trees and NFTG trees which were the same species were used in this analysis.
2. Based on internode counts taken in the field.
3. Based on laboratory tree ring analysis of basal disk.
4. P values of less than 0.05 indicate a significant difference in true age of the FTG and NFTG trees of the same species within the same plot, based on a paired comparison t-test.

increment analysis and the two height increment measurements per tree which would have generated multiple height-age and RCD-age data pairs per tree (this would have increased sample size, but would also result in unplanned autocorrelation).

Initial non-linear regression analysis determined the strength of the relationship for Height-Age and RCD-Age curves for FTG and not-FTG trees, for selected species-area combinations (determined by adequate sample size), based on the field-estimated (uncorrected) ages. Only relatively "simple", one to three term models were evaluated. For analysis of jack pine and black spruce in the Northwest, Western and Pine Falls areas, and white spruce in the Western area, r^2 values ranged from 0.12 to 0.46 and 0.13 to 0.53 for the FTG and not-FTG groups, respectively. For similar analysis based on tree height *versus* age, the r^2 values ranged from 0.14 to 0.79 and 0.20 to 0.75 for the FTG and not-FTG groups, respectively. In most cases, the power function yielded the highest r^2 values.

In most cases, due to scatter of the data, the curves were not significantly different (i.e., the regression confidence limits overlapped for FTG compared to not-FTG and in some cases, the actual regression curves overlapped). While plots of the regressions gave separate growth curves for most FTG groups in contrast to not-FTG groups, many of them had overlapping 95% confidence bands. This was because of a great degree of overlap in the individual data points between the FTG and not-FTG groups. The functions which describe these fitted curves were then used to estimate height and RCD of FTG and not-FTG trees at 10 and 15 years of age. Because of the data dispersion, the estimated size differences were not great.

The second approach used to determine whether there were significantly-different growth trajectories for FTG and not-FTG trees over time used the actual data values rather than curve fitting. Another difference was that the data for each species was pooled for all areas, and corrected ages were used. Plots of mean height for each age and mean RCD for each age, for the corrected ages tree ring-determined FTG and not-FTG trees (i.e., using true ages) was done for each species, for all areas combined. The results are shown in Figures 1-6. Only those ages where there were more than five trees represented are plotted. The mean values were usually larger for FTG compared to not-FTG trees, but some plots showed fluctuations over age, partly due to small sample sizes for some ages. The standard error bars indicated that most of the FTG/not-FTG curves did not significantly overlap.

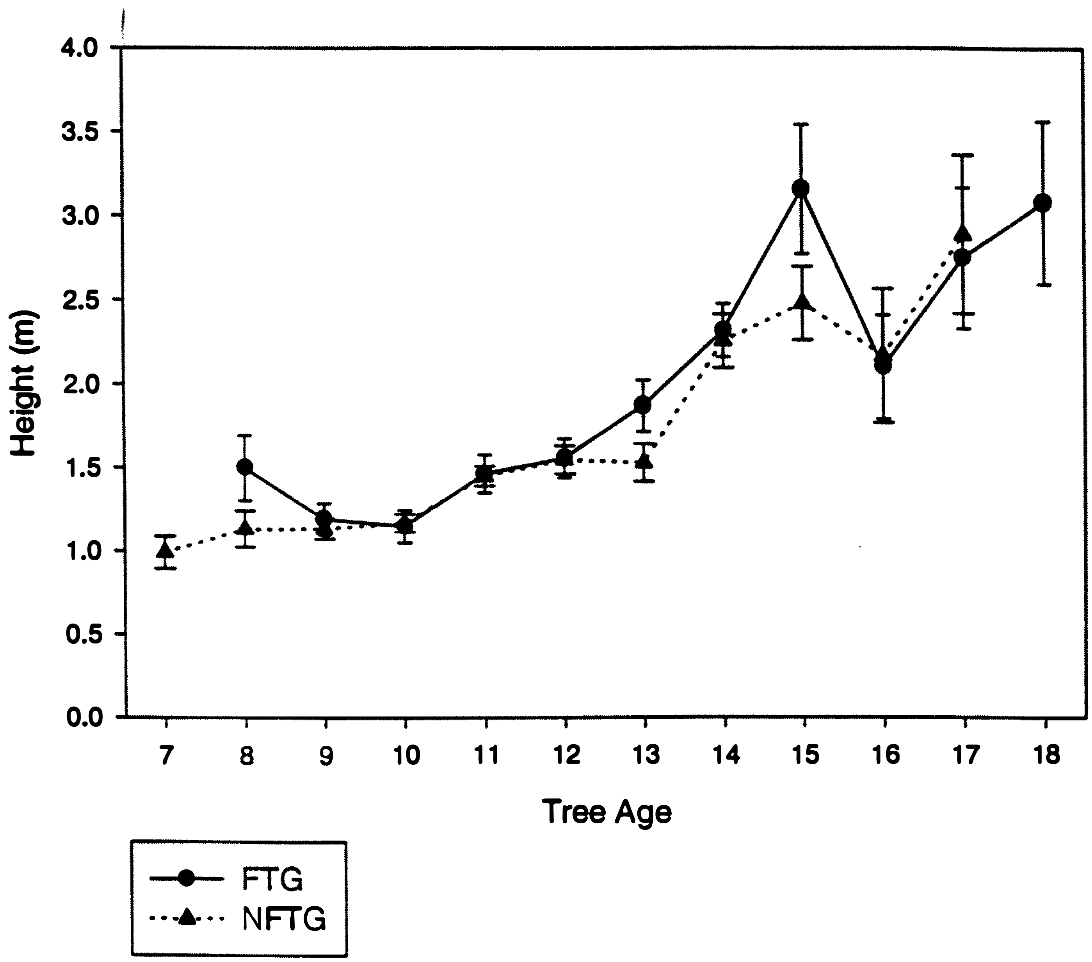
Analysis determined if there were significant differences in the size of FTG trees compared to the not-FTG trees of the same age. In these tests an age range of 10-14 years was used, as it conforms to the timing of FTG stand tending decisions and combining several years increased the sample sizes. Tests for normality indicated that at least half of the data subsets were not normal so the Wilcoxon test (a non-parametric equivalent to the paired T-Test) was done, with results shown below the graphs. All differences were significant at $P<0.05$, except for black spruce height growth. Black spruce height growth for FTG trees may have been affected by frost or insect damage - conditions often associated with open-grown trees (Bell 1991).

4.3 Effect of Competition Levels and Site Conditions on Growth of Conifer Trees

In general, the level of hardwood competition were not high, given the 10-14 year average age of the blocks. Table 5 summarizes the regeneration characteristics by area. Percent hardwood cover ranged

Figure 1

Black Spruce Height Growth

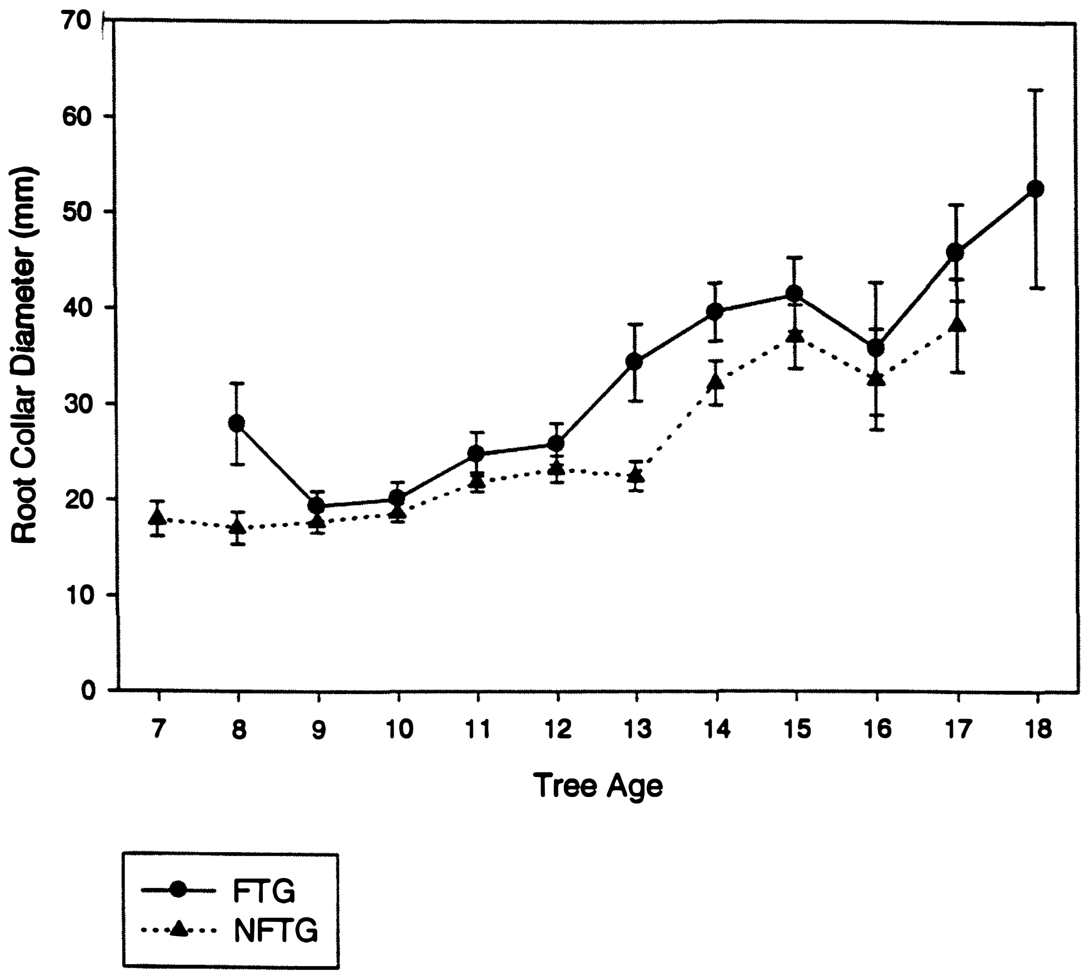


The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The height of the 10-14 year old trees is not significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 Year Old FTG Trees: N=122 Mean=1.68 m
For 10-14 Year Old Not FTG Trees: N=221 Mean=1.49 m
P value = 0.0688 (where $P<0.05$ is deemed to indicate a significant difference).

Figure 2

Black Spruce Root Collar Diameter Growth

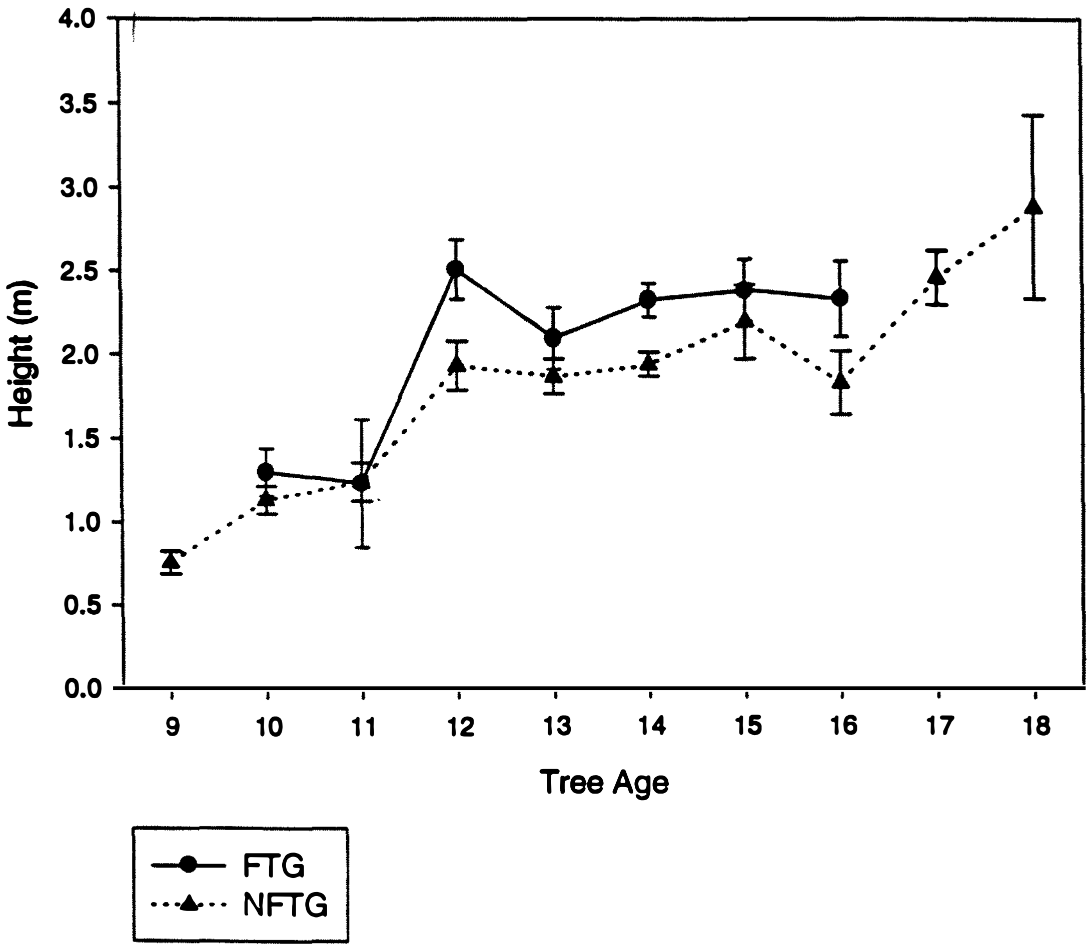


The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The root collar diameter of the 10-14 year old trees is significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 Year Old FTG Trees: N=122 Mean=28.7 mm
For 10-14 Year Old Not FTG Trees: N=221 Mean=22.5 mm
P value = 0.0004 (where $P<0.05$ is deemed to indicate a significant difference).

Figure 3

White Spruce Height Growth

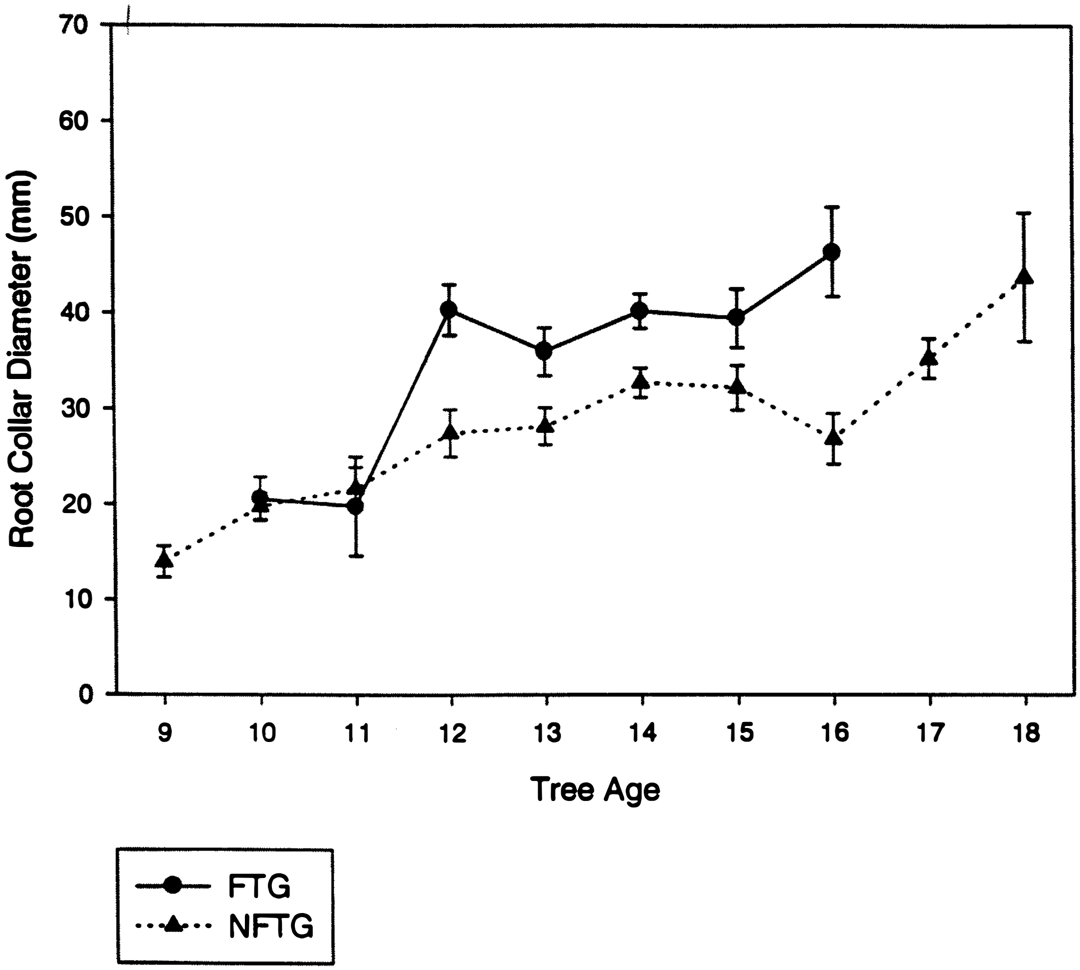


The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The height of the 10-14 year old trees is significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 FTG Trees: N=68 Mean=2.16 m
For 10-14 Not FTG Trees: N=124 Mean=1.75 m
P value = 0.0001 (where $P<0.05$ is deemed to indicate a significant difference).

Figure 4

White Spruce Root Collar Diameter Growth

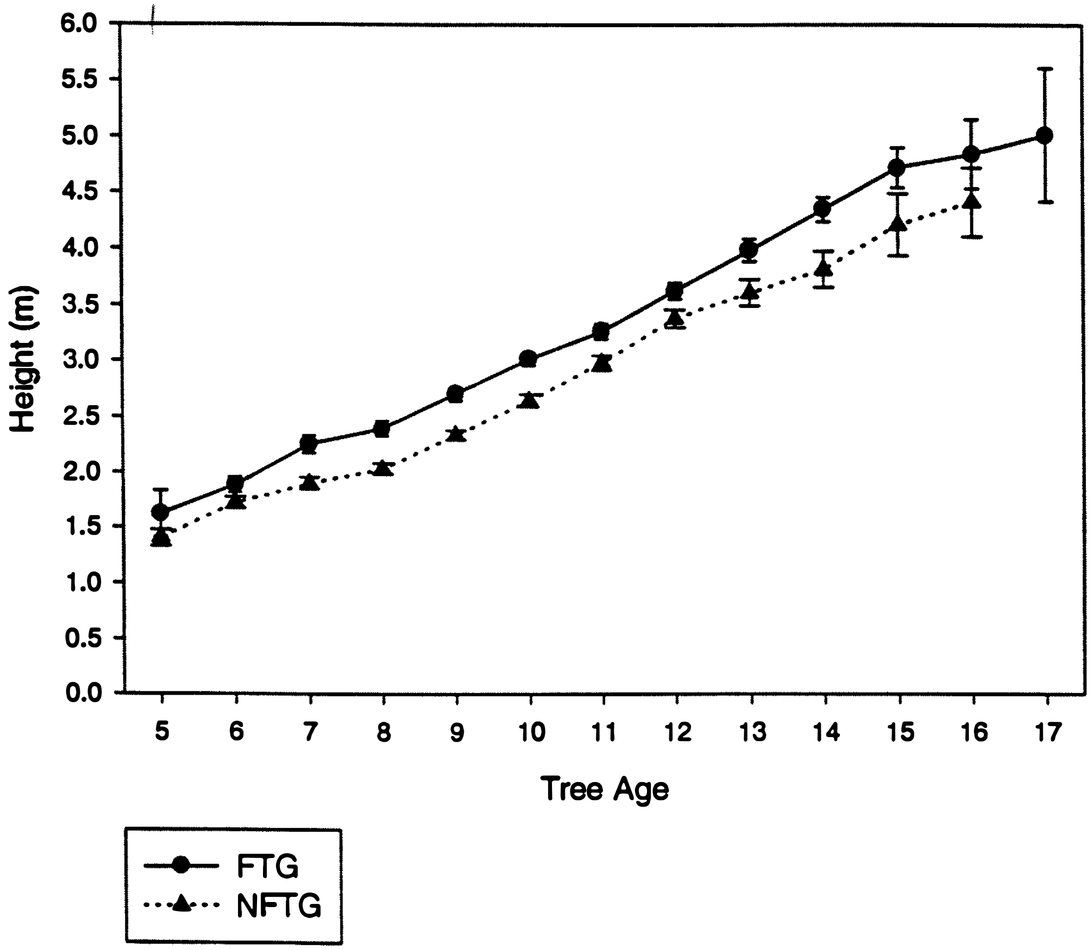


The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The root collar diameter of the 10-14 year old trees is significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 Year Old FTG Trees: N=68 Mean=36.6 mm
For 10-14 Year Old Not FTG Trees: N=124 Mean=27.8 mm
P value = 0.0001 (where P<0.05 is deemed to indicate a significant difference).

Figure 5

Jack Pine Height Growth

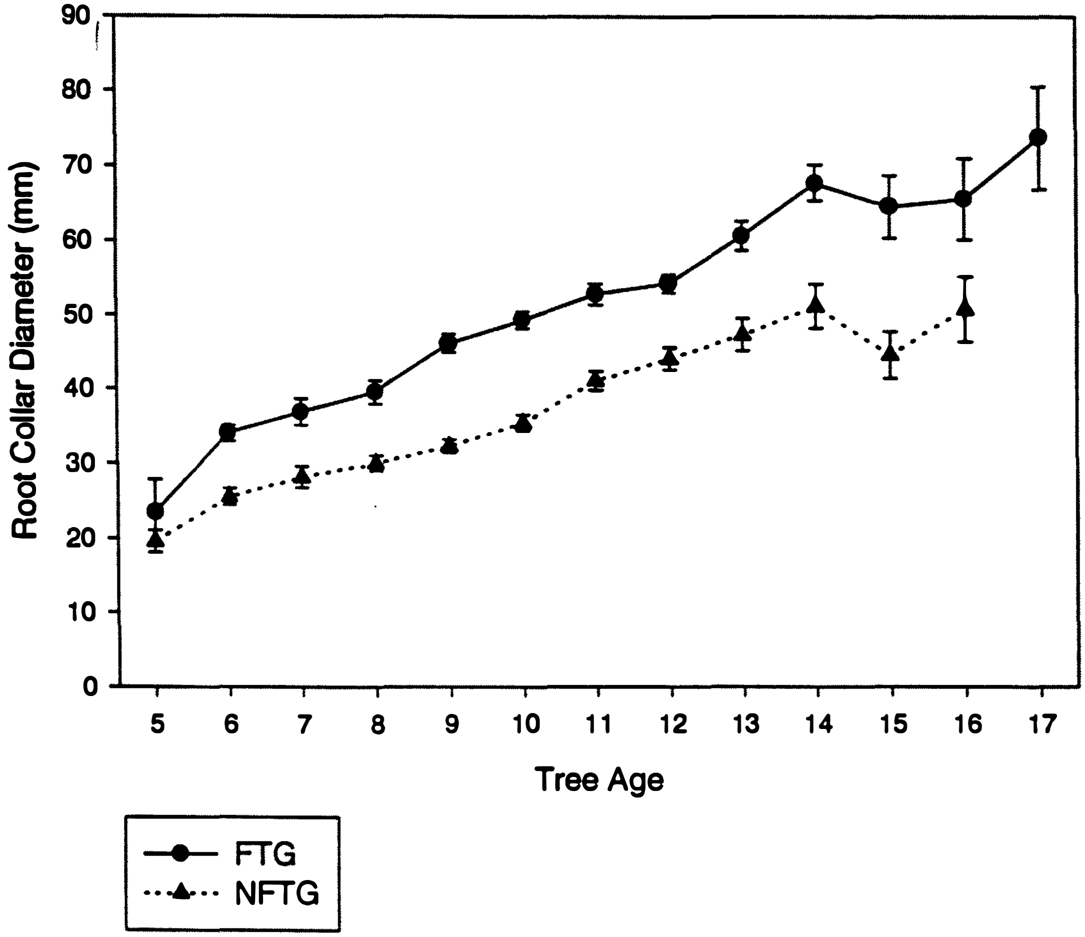


The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The height of the 10-14 year old trees is significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 Year Old FTG Trees: N=518 Mean=3.50 m
For 10-14 Not FTG Trees: N=429 Mean=3.09 m
P value = 0.0001 (where $P<0.05$ is deemed to indicate a significant difference).

Figure 6

Jack Pine Root Collar Diameter Growth



The plots show the mean and standard error for trees of each age, based on the tree age after tree ring analysis correction. The curves do not increase constantly with age because each age point represents a different group of trees. Only points which are represented by at least five trees are shown.

The root collar diameter of the 10-14 year old trees is significantly different for FTG vs NFTG groups, based on the Wilcoxon (non-parametric) test.
For 10-14 Year Old FTG Trees: N=518 Mean=54.9 mm
For 10-14 Year Old Not FTG Trees: N=429 Mean=41.4 mm
P value = 0.0001 (where $P<0.05$ is deemed to indicate a significant difference).

Table 5
Regeneration Characteristics by Area

	Area				
	Pine Falls	Eastern	Central	Western	Northwest
Blocks	22	7	3	26	33
Plots	399	60	50	556	837
Hardwood Cover (%)[1]	11.33 ±(0.84)[2]	6.76 ±(1.45)	9.35 ±(1.66)	14.13 ±(0.72)	11.15 ±(0.44)
Hardwood Height (m)[1]	3.12 (0.11)	2.91 (0.19)	2.50 (0.16)	3.12 (0.07)	3.08 (0.06)
Shrub Cover (%)	19.39 (1.16)	29.05 (30.4)	6.42 (1.29)	6.80 (0.49)	4.71 (0.29)
Shrub Height (m)	1.24 (0.04)	1.56 (0.10)	0.78 (0.07)	1.14 (0.03)	1.01 (0.26)
Conifer Stocking Density (stems/ha)	2907 (182)	2346 (286)	3970 (275)	3240 (149)	6204 (197)
Conifer Stocking Height (m)	1.94 (0.11)	2.61 (0.35)	3.08 (0.27)	2.46 (0.15)	2.14 (0.08)
Hardwood Stocking Density (stems/ha)	1852 (127)	1625 (341)	1565 (238)	4655 (191)	3731 (134)
Hardwood Stocking Height (m)	2.98 (0.17)	2.36 (0.37)	1.92 (0.12)	3.00 (0.12)	3.00 (0.12)
Well-spaced Conifer Density (stems/ha)	931 (32)	992 (76)	1800 (88)	1173 (33)	1292 (25)
Well-spaced Conifer Height(m)	2.18 (0.12)	2.72 (0.41)	3.08 (0.27)	2.71 (0.25)	2.43 (0.09)
Well-spaced Hardwood Density (stems/ha)	225 (21)	138 (43)	25 (21)	368 (24)	243 (15)
Well-spaced Hardwood Height (m)	3.62 (0.26)	3.05 (1.95)	-[4]	3.46 (0.25)	3.29 (0.22)
FTG Conifer Density (stems/ha)	558 (31)	454 (64)	1125 (756)	549 (32)	656 (25)
FTG Conifer Height (m)	2.40 (0.16)	3.14 (0.49)	3.20 (0.22)	2.97 (0.17)	2.70 (0.10)
FTG Age[3]	10.95 (0.29)	12.80 (0.67)	11.13 (0.24)	14.40 (0.28)	10.81 (0.12)

1. Based on all hardwoods in the plot. Hardwood and shrub abundance was based on an estimate of shoot cover, rather than canopy cover (the latter would give larger numbers). Prior to analysis, the cover estimates for each plot were converted from cover classes, to mid-class values (e.g., cover class 2: 1-5% is converted to a value of 3%).
2. Mean and standard error of the mean.
3. Age is after correction based on tree-ring analysis.
4. No data collected.

from 6.8% to 14.1% with hardwood stocking ranging from 1,565 stems/ha to 4,655 stems/ha. Many of the competition-growth relationships were shown to be statistically significant, but in most cases, the majority of the variance in FTG conifer growth was not captured in the regression models. Multiple linear regression analysis stratified by FTG species for all areas combined on untransformed variables indicated that hardwood and shrub cover and density in the 40 m^2 plots usually explained less than 10% of the observed variation in growth of the FTG conifer in the plot (maximum r^2 was 0.11). Hardwood abundance was used as a covariant in some regression models which determined the relationship between FTG tree size and site location and conditions. In some of these models, hardwood competition variables added significantly to the models, but the results varied depending on the species and variable combination used.

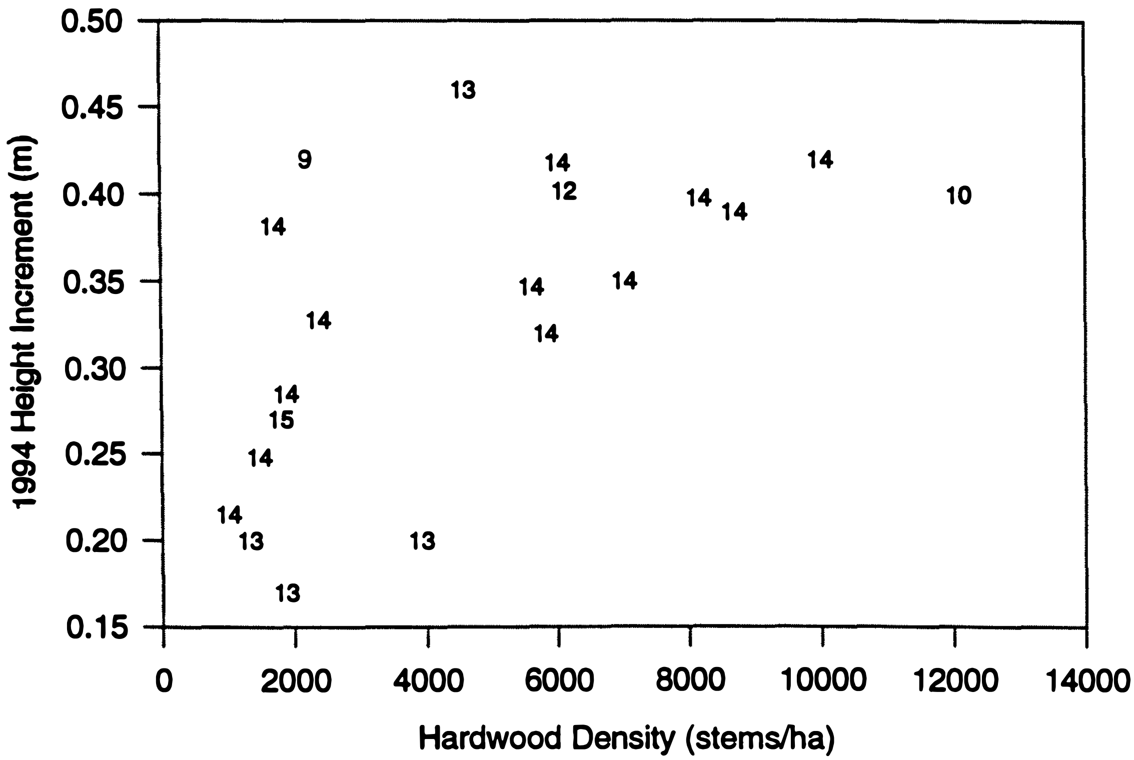
Analysis of covariance using transformed data, stratified by area showed in most cases the variation in competition levels was significant between blocks but not within blocks. When the analysis was done to determine the effect of drainage class on competition levels, there was a significant effect ($P< 0.001$), but with low r^2 in most models. For moisture classes, the significant relationships were less common.

Non-linear regression analysis based on block-level averages for hardwood competition *versus* FTG tree growth showed higher r^2 values, up to 0.60 (76 blocks for jack pine, 23 blocks for white spruce and 37 blocks for black spruce). However, in many cases, there was a positive relationship between hardwood competition level and conifer tree growth, as shown in the example for hardwood stocking number *versus* 1994 height increment for FTG white spruce (Figure 7). The curve fit to that data was commonly seen in the analysis; strongly positive relationship at lower competition levels with a leveling off at higher competition levels (e.g., hardwood densities over 10,000 stems/ha). There may have been three possible explanations for this trend. 1) The blocks represented by lower hardwood densities may have been younger blocks and would normally have trees with smaller height increments. The block ages plotted on Figure 7 indicate that blocks with low densities are, in fact, not younger than average. 2) The second explanation is that because these were FTG trees (i.e, on microsites within the block that did not have a lot of competition), an increase in overall block-level hardwood stocking should have little impact on height increment. If this was the case, then one would expect that a similar plot of hardwood stocking *versus* height increment of not-FTG trees (i.e., trees under some competition) would show a negative relationship. While the relationship is not as strong as with FTG trees, it is still positive (Figure 8). 3) The third explanation is that an increase in hardwood density may indicate a more productive site, and thus both hardwoods and conifers would benefit. Figures 9 and 10 show the hardwood stocking-white spruce height increment for FTG and not-FTG trees, with site quality indicated on the plotted values. There is no trend towards better site quality with greater hardwood densities.

It is important to note that this trend is not obvious for all growth variables. However, in linear regression analysis using block-level competition and growth relationships, at least half the regressions with r^2 values greater than 0.20 indicated this positive relationship. In most cases, increases in conifer growth leveled off at moderate levels of hardwood competition. The positive trends were due in most part to poorer growth for conifer trees with no hardwoods on the block. While there was a positive relationship between average conifer tree growth with average competition levels in each block (due to factors discussed below), it was felt that the maximum conifer growth potential would be associated with plots in which there were no nearby conifers. In

Figure 7

Relationship Between Hardwood Density and Free-to-Grow White Spruce Height Increment
Based on Block-Level Averages - With Block Age Indicated



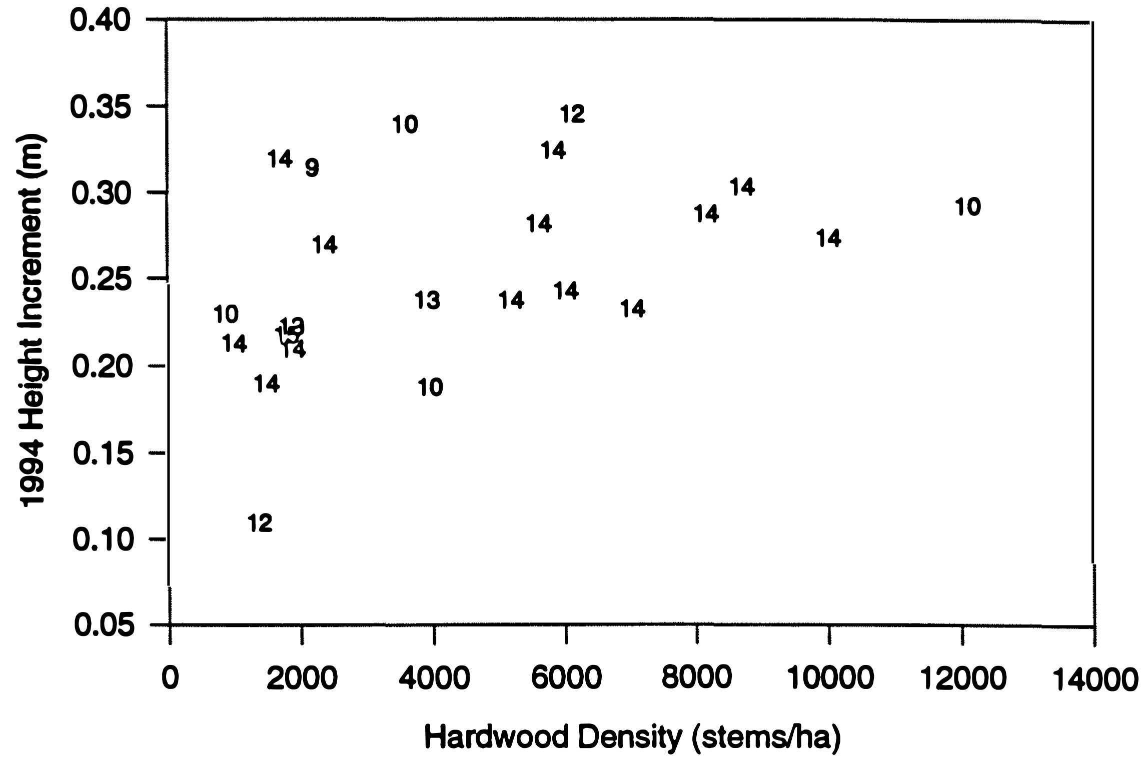
Symbols represent block age.

Based on 20 blocks. The number of plots represented varies between blocks, because only those plots with a measured white spruce FTG tree are included.

Regression Model: Height Inc = 0.49 - 0.57/Hardwood Density$^{0.5}$
$r^2 = 0.44$ Fstat = 14.46

Figure 8

Relationship Between Hardwood Density and Not-Free-to-Grow White Spruce Height Increment Based on Block-Level Averages - With Block Age Indicated



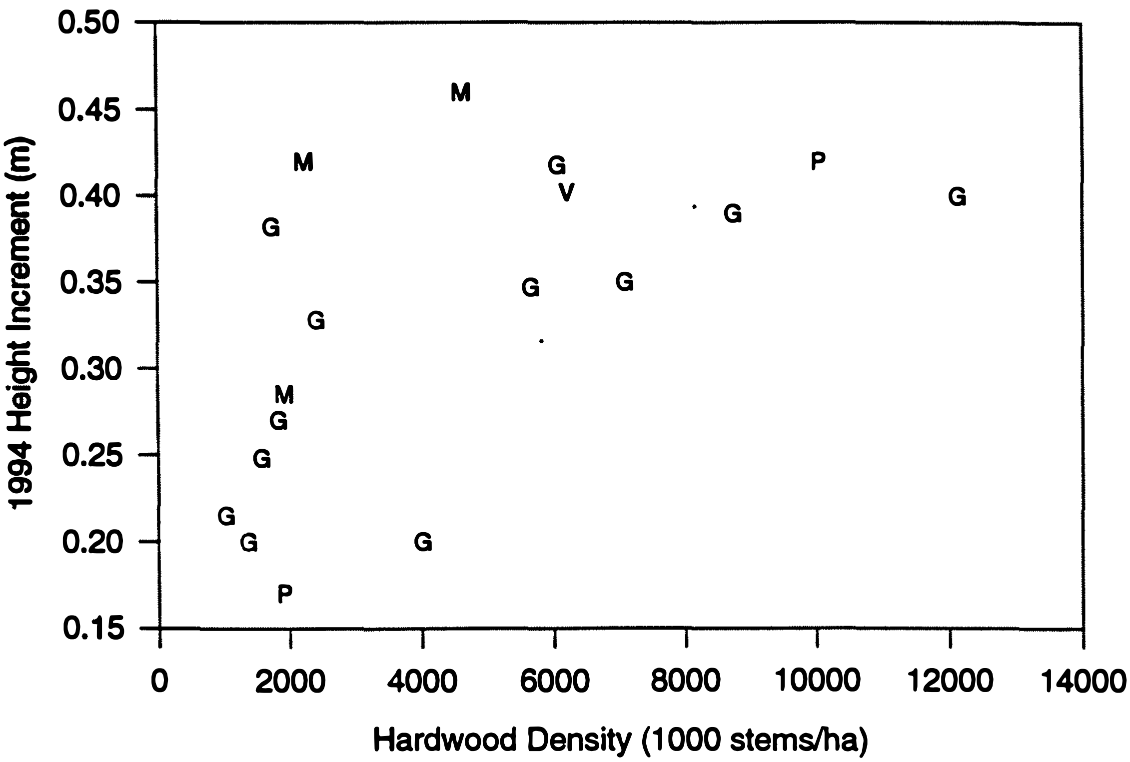
Symbols represent block age.

Based on 23 blocks. The number of plots represented varies between blocks, because only those plots with a measured NFTG white spruce are included.

Regression Model: Height Inc = 0.33 - 0.26/Hardwood Density$^{0.5}$
$r^2 = 0.24$ Fstat = 6.71

Figure 9

Relationship Between Hardwood Density and Free-to-Grow White Spruce Height Increment
Based on Block-Level Averages - With Site Quality Indicated



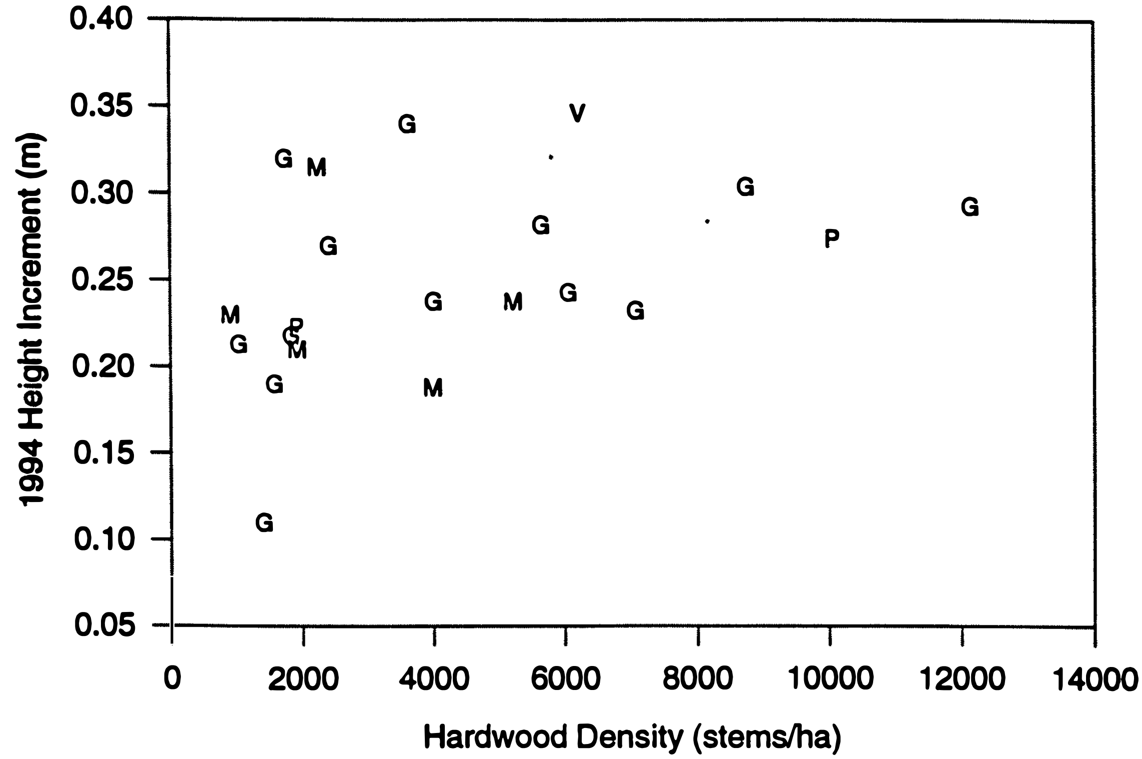
Symbols represent subjective site quality assessment.
P-poor, M-medium, G-good, V-very good, . - no data.

Based on 20 blocks. The number of plots represented varies between blocks, because only those plots with a measured white spruce FTG tree are included.

Regression Model: Height Inc = 0.49 - 0.57/Hardwood Density$^{0.5}$
$r^2 = 0.44$ Fstat = 14.46

Figure 10

Relationship Between Hardwood Density and Not-Free-to-Grow White Spruce Height Increment
Based on Block-Level Averages - With Site Quality Indicated



Symbols represent subjective site quality assessment.
P-poor, M-medium, G-good, V-very good, . - no data

Based on 23 blocks. The number of plots represented varies between blocks, because only those plots with a measured NFTG white spruce are included.

Regression Model: Height Inc = 0.33 - 0.26/Hardwood Density$^{0.5}$
$r^2 = 0.24$ Fstat = 6.71

other words, the biggest trees on the block would be in a fully open-grown state. Analysis was done to compare the maximum growth of FTG trees on the block with the hardwood competition level on each block. For some species, maximum growth was not at the minimal hardwood levels, but at between 1-15% hardwood cover (Figure 11), although the results were not statistically significant. While block age may have been a factor because trees in the smaller hardwood cover category may have been from younger blocks (jack pine example in Figure 11), in other cases this wasn't a factor (black spruce example in Figure 11).

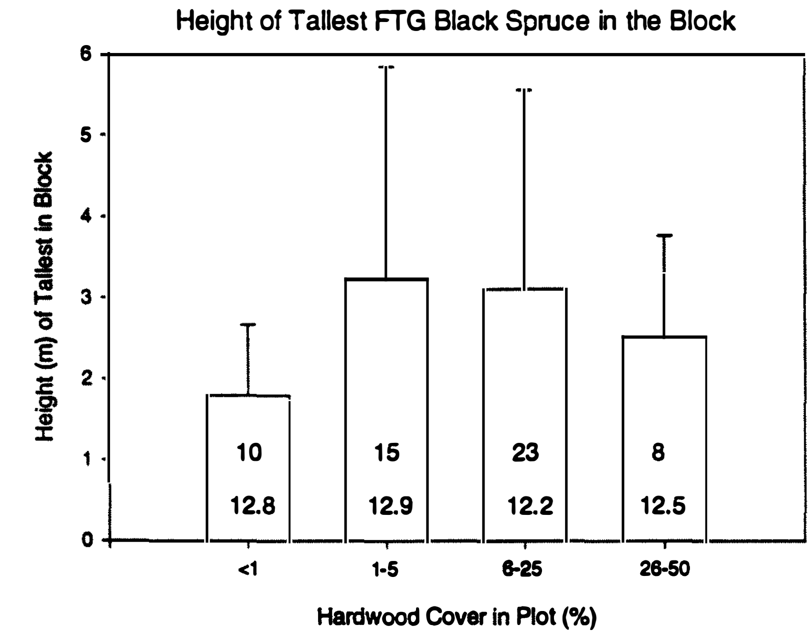
The above results appear to contradict the fact that FTG trees grew better than not-FTG trees (see Figures 1-6), in which better growth was associated with less competition in the immediate area. In fact, conifer seedlings that met the FTG distance and height thresholds could have hardwoods associated with them, though not in the immediate area (within 1 m). While it is well known that seedling growth is poor under low light levels, there is evidence that some competition may be beneficial for growth of regenerating spruce trees (Bell 1991). Height increment of young white spruce seedlings isn't affected until understorey light levels are less than 40% of full sunlight (Lieffers and Stadt 1994). For older understorey white spruce up to 50 years old, one study showed that there are not excessive height reductions under moderate canopy cover (Lieffers et al. *in press*).

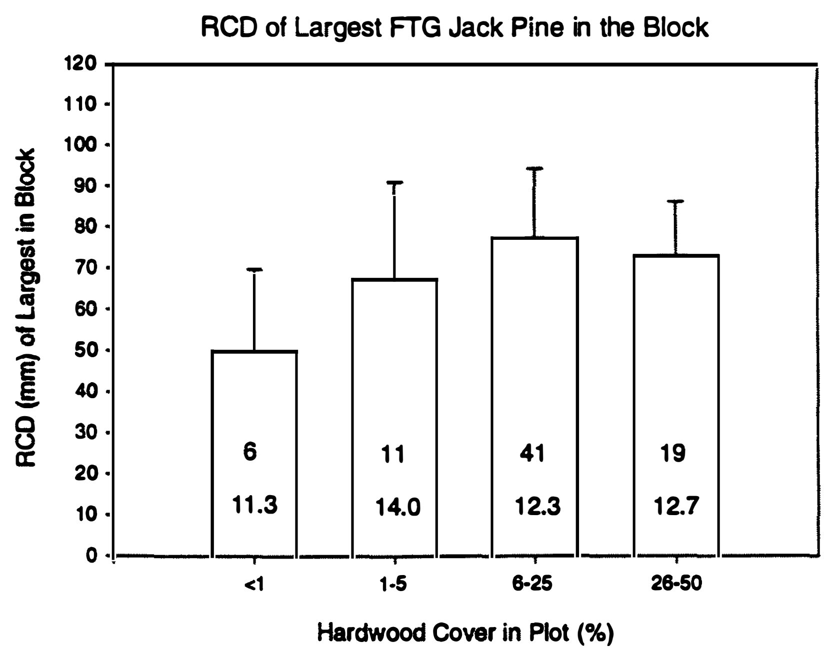
Even for shade intolerant species such as lodgepole pine, low levels of hardwood competition are shown to be beneficial (Newsome 1995). This may be related to the fact that damaging agents are often more severe on highly productive sites (Ives and Rentz 1992), and that some cover may reduce their impact.

The idea is that while maximum growth of individuals may theoretically be achieved at the full light conditions, the best average growth on the block is achieved at some small level of competition. In the absence of other factors, growth potential for conifers may be highest in areas with no competition, there are other factors which may negatively affect those open-grown trees. These conclusions relate to the regeneration phase of the tree establishment; namely, that some competition is beneficial to conifer growth. What is not known from this study is the appropriate amount of hardwoods to keep on the site so that competition does not become a problem at a later date. The problem is that we are looking at a snapshot of a dynamic system. Moderate amounts of hardwood competition at age 14 may become overwhelming at age 30. Pine will maintain height, but with only small crown areas, and so may eventually be shaded out if there is too much competition.

In young regenerating stands, some vegetation control to remove hardwood competition is desirable; and the FTG standards are an appropriate way to achieve this. However, there is evidence that some hardwood regeneration should initially be left on the site, because, in many blocks, the maximum conifer growth on the block and the best average growth was associated with a low to moderate level of aspen competition. Later on in stand development, the relatively fast-growing hardwoods may have significant negative effects on conifer growth. For example, Yang (1991) illustrates significant increase in growth of white spruce 35 years after release from aspen. The white spruce that were not released showed growth suppression due to shade and leader damage by adjacent hardwoods. These results indicate that although young conifers may benefit from some hardwood cover, as aspen crowns develop, a second stand tending may be required to ensure optimal conifer growth.

Figure 11
Relationship Between the Size of the Largest Free-to-Grow Conifer in Each Block and the Hardwood Competition Around these Largest Trees





The upper number in the bar is the number of plots represented by each hardwood class. The lower number is the average block age of those plots.

Bars indicate mean values, with standard error of the mean (upper interval only). Means not significantly different at P=0.05 for Tukey's studentized range test (SAS Institute Inc. 1990).

5.0 CONCLUSIONS

Tree ring analysis on approximately 20% of the trees indicated that there was no significant age bias in the field aging of FTG trees in comparison to not-FTG trees, based on internode counts. There were however, small discrepancies in the field-estimated ages compared to the tree ring-determined ages, and appropriate age corrections were applied prior to analysis.

Height and RCD growth curves and statistical tests showed that the height and RCD of 10-14 year old FTG trees was significantly larger than the not-FTG trees for all species, except for black spruce height. This validates the use of the hardwood competitor distance and height thresholds as defined for the Free-To-Grow survey protocol used in this study, for the species and sites sampled.

In regenerating stands, vegetation control to remove some hardwood competition is desirable if the objective is to enhance conifer growth and stand tending based on FTG standards may be one important method to achieve this. However, there is evidence that some hardwoods should be left on the site because in many cases, the maximum conifer growth on the block and the best average growth is associated with a low to moderate level of aspen competition. Due to varying growth rates for different conifer and hardwood species, stand tending may be required later on to reduce the negative effects on conifer growth from overtopping hardwoods.

ACKNOWLEDGMENTS

Jeff Delaney from the Manitoba Forestry Branch in Winnipeg Manitoba was involved in all aspects of this project. Todd Ringash, Julie Nightingale and Andy Grauman of the Manitoba Forestry Branch assisted in supervision of the field crews. Andrea Hagan helped produce the final version of this report. The help of the above-named individuals along with the summer students who collected the data in 1994 is gratefully acknowledged.

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Appendix 1

Example of the Data Sheet

FG-2/94

FREE TO GROW SURVEY FORM Page____ of____

INPUT BLOCK #

----------NUMBERS BELOW ARE STEMS/PLOT----------

LINE PLOT	STRATA SUMMAR	SPP	HT	%	CONIFER STOCKING	HARDWOOD STOCKING	WELL SPAC. CONIFER	W.S. HW	FTG CONIFER		SPP	HT (m)	94 (m)	93 (m)	RCD (mm)	AGE EST	DISK
	SHRB									FTG							
	HW									NFTG							
				HT(CM)													
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
				HT (CM)													
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	
	SHRB									FTG							
	HW									NFTG							
COMMENTS																	

Appendix 2

Number of Free-to-Grow and Not-Free-to-Grow Trees with Measurements and Tree-Ring Analyses by Species and Area

Species	Area	Free-to-Grow Trees		Not-Free-to-Grow Trees	
		Measured in Field	Tree Ring Analysis in Lab	Measured in Field	Tree Ring Analysis in Lab
Black Spruce	Pine Falls	71	24	92	29
	Eastern	16	5	22	6
	Central	0	0	0	0
	Western	70	21	117	26
	Northwest	54	17	124	23
	All	**211**	**67**	**355**	**84**
White Spruce	Pine Falls	9	7	26	11
	Eastern	0	0	5	1
	Central	0	0	0	0
	Western	89	41	162	44
	Northwest	3	0	8	1
	All	**101**	**48**	**201**	**57**
Jack Pine	Pine Falls	152	49	106	41
	Eastern	19	6	19	5
	Central	46	10	37	10
	Western	145	42	147	43
	Northwest	504	154	525	148
	All	**866**	**261**	**834**	**247**
Balsam Fir	Pine Falls	4	1	8	0
	Eastern	0	0	0	0
	Central	0	0	0	0
	Western	17	7	26	6
	Northwest	0	0	0	0
	All	**21**	**8**	**34**	**6**
Tamarack	Pine Falls	11	2	13	3
	Eastern	1	0	1	0
	Central	0	0	0	0
	Western	6	1	3	0
	Northwest	1	0	0	0
	All	**19**	**3**	**17**	**3**
TOTAL		**1218**	**387**	**1441**	**397**

Appendix 3

Age Correction Based on the Difference Between True Ages and Field-Estimated Ages of Free-to-Grow *Versus* Not-Free-to-Grow Trees

Species	Class	Area	N	Estimated Mean Age[1]	True Mean Age[2]	Age Difference[3] (True-Est.)	Age Correction[4]
BS	FTG	Pine Falls	23	12.2	13.6	1.7	
		Eastern	5	15.4	16.6	1.2	
		Central	0	-	-	-	
		Western	20	11.6	14.2	2.6*	
		Northwest	17	10.7	14.1	3.4	
		All	65	11.9	14.1	2.4*	2
	NFTG	Pine Falls	29	9.7	10.9	1.2*	
		Eastern	6	12.0	14.3	2.3	
		Central	0	-	-	-	
		Western	26	12.2	13.6	1.5*	
		Northwest	23	12.3	11.8	-0.5	
		All	84	11.3	12.2	0.9*	1
JP	FTG	Pine Falls	48	8.7	9.0	0.4	
		Eastern	6	10.2	10.2	0.0	
		Central	10	10.9	11.4	0.5	
		Western	42	12.9	12.6	-0.3	
		Northwest	152	10.2	10.2	0.0	
		All	258	10.4	10.4	0.0	0
	NFTG	Pine Falls	41	8.1	8.5	0.4	
		Eastern	5	8.8	8.8	0.0	
		Central	10	11.0	11.5	0.5	
		Western	43	12.0	11.9	-0.1	
		Northwest	147	9.5	9.9	0.4*	
		All	246	9.7	10.0	0.3*	0
WS	FTG	Pine Falls	7	16.6	18.3	1.7	
		Eastern	0	-	-	-	
		Central	0	-	-	1.6*	
		Western	40	11.6	13.2	-	
		Northwest	0	-	-	1.7*	
		All	47	12.3	14.0		2
	NFTG	Pine Falls	11	14.1	16.6	2.5	
		Eastern	1	8.0	9.0	1.0	
		Central	0	-	-	-	
		Western	43	11.8	13.5	1.7*	
		Northwest	1	11.0	11.0	0.0	
		All	56	12.1	13.9	1.8*	2

1. Based on internode counts taken in the field.
2. Based on laboratory tree ring analysis of basal disk.
3. Significant differences ($P < 0.05$) in the true vs estimated age of the trees, based on a paired compa son t-test for each tree are shown by a * .
4. Age correction is applied on species by class basis.