University of Alberta

The Role of Forest Stand Structure in Predicting Yield

by

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Abstract

Three growth model predictions were compared to actual Saskatchewan permanent sample plots (PSP). The Saskatchewan provincial yield curves under-predicted growth, the Dendron/Flewelling was the most robust model, and the Mixedwood Growth Model slightly over-predicted yield but was the most versatile model. Growth models developed using PSPs tend to over-predict actual landscape level yield due to data collection bias. The use of canopy cover as a mechanism to adjust model predictions was investigated. Similar pure aspen and white spruce dominated inventory polygons were stratified, from aerial photographs, into 10% canopy cover classes and sampled. The results show that the relationship between canopy cover and plot volume was significant but weak. The addition of other variables such as top height and merchantable density improved the models significantly. The results show that structural differences within polygons, not described by the inventory, play a major role in modeling yield differences.

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Chapter 1. Introduction

In Canada there is a need for sound information concerning forest growth. This information is required so that both governing bodies and companies are able to set sustainable annual harvest levels. Several growth and yield models have been developed for the boreal mixedwood forests of Saskatchewan and Alberta. These models can be used to create Yield Curves needed for use in Timber Supply Analysis.

Since all growth and yield models are simplifications of complex systems and are based on a set of assumptions and simplifications of the real stand dynamics several questions arise. The questions every manager or decision maker is confronted with are: 1) What model to use? 2) What are the model limitations and the risks associated with the use of any particular model?, and, 3) How much confidence can one have in a model's predictions?

Model validation is the process that constitutes the basis for answering these questions. Model validation is typically done by the developers themselves using an independent dataset not used in the model development. A similar approach is to use a single dataset and compare the predictions of several growth and yield models to the actual data (Bokalo, 1994).

However, a major concern for the growth and yield model users is that models based on Permanent Sample Plots (PSP) tend to over-predict the landscape forest level yield. Temporary Sample Plots (TSP) are currently used to quantify the actual landscape level yield. However, the PSP based growth and yield models are starting to be preferred in determining yield especially for young post harvest strata with no data past 40 years.

The discrepancies between a PSP based growth and yield model and the landscape yield values have several sources. In Alberta for example, the Mixedwood Growth Model (MGM) was developed using data from permanent sample plots that were biased towards accessible locations and fully stocked stands unaffected by biotic (insects, disease) and abiotic factors (windthrow). Therefore they do not provide an unbiased sample of the landscape (Bokalo, 1994). MGM is a distance-independent individual tree model (Bokalo, Stadt, and Titus, 2005) which assumes even distribution of trees. This can often conflict with the "true" spatial distribution of trees at the landscape level, since the model does not account for clumps or gaps. Furthermore, the model predictions are applied to inventory polygons from Alberta Vegetation Inventory (AVI). AVI delineates polygons based on aerial photographs and criteria outlined in Alberta Vegetation Inventory Standards Manual (AEP, 1994). The yield in these polygons is more variable (heterogeneous) than the model predictions based on fully stocked PSP. Quantifying the yield differences between differently stocked polygons is the first step in developing a Volume Loss Factor (VLF) needed to adjust MGM predictions.

This thesis endeavors to address some of the questions related to the applicability of three growth and yield models calibrated for use in Saskatchewan. Chapter 2 compares the predictions from three models with actual re-measured data from Saskatchewan Permanent Sample Plots and discusses the limitations and the accuracy of predictions for each model.

Chapter 3 explores potential development and use of indices that relate polygon mean volume to polygon heterogeneity expressed as stocking variation. This index could then be calibrated as an estimate of Volume Loss Factor. A first step was to quantify the relationship between yield and canopy cover as a measure of stocking. Several other relationships using field measured variables were tested in order to explain volume. Understanding Volume Loss Factors can be very helpful for adjusting MGM predictions to landscape level yields. The results from this study will help better understand the landscape's yield structure and what variables can be used to adjust model predictions.

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Chapter 2. Evaluating the predictive performance of several growth models calibrated for Saskatchewan

2.1 Introduction

It is a common practice to evaluate a model's predictions against an independent dataset not used in the model development (Bokalo, 1994). All developed models are usually evaluated by the developers themselves (Bokalo, 1994; Dendron and Flewelling, 1995b), based on an independent dataset. The evaluation process has a double role; it assures the users that the model is predicting within a certain tested range and it informs the developers on potential biases embedded within the model.

A different type of assessment is to use an independent dataset and compare several models' predictions to actual plot re-measurements. Bokalo (1994) used a sample of Permanent Sample Plots from Alberta to evaluate the predictions of three growth models calibrated for use in Alberta.

Several growth and yield models have been developed for use in the province of Saskatchewan. However, no evaluation of these models is available to guide and inform the users of the models' limitations and abilities. Three models were selected for evaluation:

1). ***The Saskatchewan Provincial Yield Curves*, based on the Saskatchewan Department for Environment and Resource Management (SE) 3P Sampling Program, (Golder, 2001).**

2). ***The Dendron and Flewelling Growth Model*; Preliminary natural stand growth and yield estimation for Saskatchewan, based on the province's existing permanent sample plots (PSP) system (Dendron and Flewelling, 1995a).**

3). ***The Mixedwood Growth Model* (MGM 2005) created by S. J. Titus at the University of Alberta (Bokalo, Stadt, and Titus, 2005). The model is based on the Alberta PSP system and has been calibrated for Saskatchewan.**

The objective of this study was to evaluate these models by comparing their predictions with actual growth data from the permanent sample plots provided by Saskatchewan Environment – Forest Service (SE)[1]. A simple summary of how the models are constructed, and what their presumed strengths and weaknesses are, is not enough for evaluating the capabilities of any one model. However, information on a model's structure and on the data used to build it can be useful in interpreting and understanding a model's behavior.

The three models will be briefly introduced and the modeling process presented. The methods and analysis together with the data used in the comparison will be presented next. Results by species group will constitute the basis for further discussions. The analysis will focus on the limiting factors (data and model related) that influenced the results. Conclusions will be drawn concerning each model's abilities to predict actual growth of the Saskatchewan PSPs.

2.2 Description of the Growth Models

2.2.1 Saskatchewan Provincial Yield Curves

Saskatchewan is currently divided into thirteen inventory zones. The objective for constructing the yield curves was to have a criterion for setting the annual harvest levels. The constructed yield curves pertained to seven inventory zones. Five of them, for inventory zones C10, C20, C30, C40 and C50, were constructed by Golder Associates using temporary sample plots data from Saskatchewan Environment 3P Sampling Program. The yield curves for the inventory zones C60 and C70 were developed using temporary sample plots provided by SE in collaboration with Mistik Management as part of their Forest Management Plan approval process (Golder, 2001).

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[1] Previously called the Saskatchewan Department for Environment and Resource Management. For the remainder of the chapter the current name, Saskatchewan Environment – Forest Service (SE) will be used.

2.2.1.1 Yield Curves and Outputs

The developed yield curves predict the total volume of the stand at different ages as well as the volume per species group (conifer and deciduous) according to age. Tables with the curve statistics were built and contained the coefficients to obtain volume and primary volume (conifers or deciduous volume) by stratum and canopy cover class.

2.2.1.2 Model Construction

Data used to construct the model were from the 3P sampling program. The 3P plots are temporary sample plots (TSPs). Data from temporary sample plots were collected and used to compute the volume for one stand. The yield curves for the seven inventory zones (C10 – C70) were based on 16,593 plots. The data were not equally distributed among age classes, with fewer plots in younger and very old stands. Therefore age class averages were used to fit the equation. In general, the data were grouped around the central age classes (Golder, 2001).

The plots were stratified according to inventory zone (C zone), broad cover class, leading species and secondary species. Four yield curves were developed for each delineated stratum based on four classes of canopy cover (Table 2.1). After stratification and screening, for some strata and species associations the number of plots was insufficient for constructing yield curves, therefore plots from C20, C30, C40 and C50 inventory zones were amalgamated together to obtain regional curves for these zones.

The model is represented by yield curves fit on this dataset using non-linear regression. Equation (2.1) was used to fit the data.

$$Yield = a*(Age - 10)**[b + (Density - 1)*0.225*c)]*exp[-a*(Age - 10)] \quad (2.1)$$

Where:

Yield = gross volume m^3/ha.

Age = age class in decadal increments.

exp = the base of the natural logarithm

Density is assigned the dummy value of the canopy cover class (1, 2, 3 or 4).

a, b, c are coefficients determined from the non – linear regression.

2.2.2 The Dendron and Flewelling Growth Model

The model proposed by Dendron Resource Surveys Inc. and J. W. Flewelling was constructed in 1995, prior to the creation of the Provincial Yield Curves. The development had as a main objective the construction of a growth and yield modeling kit for the major species groups and species associations in Saskatchewan (white spruce, black spruce, jack pine, trembling aspen, other conifer and other deciduous), (Dendron and Flewelling, 1995a).

The model is a whole stand growth model based on per hectare net increment of three stand characteristics: quadratic mean diameter, basal area, top height. The model cannot predict juvenile growth (stands below 1.3m in height and stands with ages lower than the predefined breast height age by species). Saskatchewan permanent sample plots were used to fit the internal model's equations. The construction of the model has several embedded components: a component representing the construction of growth and yield equations for the major species associations, a component representing the construction of the growth simulation kit and a component for the validation of the results.

2.2.2.1 Modeling Framework

The modeling kit was written in FORTRAN and embedded with a set of growth and yield equations and yield tables for the main species groups. There are two possible scenarios, a validation scenario and an interactive simulator. The validation scenario was used by the developers to test the model's predictions.

For the simulator, a series of input data are needed. The simulator needs as primary information the species association as a code of two digits, the inventory zone (C-zone), the species from the stand to be modeled and the stand's site index.

Once the standard information is provided the user can choose between growing a stand from actual data and creating a stand using the model.

The user can then input the quadratic mean diameter, basal area and trees per hectare of the stand by species groups. The user finally introduces the number of years for which the stand is to be modeled and the period of increment used. Two files are created, one in a form of a journal that contains the input information and the results from each simulation and an optional output file that contains the results of the simulation. The results contain the stand characteristics, basal area, density, top height and volumes differentiated by species association and for the whole stand.

2.2.2.2 Method Used for Constructing the Model

The model uses growth equations to create growth projections from initial stand conditions input by the user or created within the model framework. The growth and yield component of the model contains: growth equations that have embedded yield equations within them, equations for top height (HTOP), and volume equations by species association.

Growth equations (for statistics summed across the species) were developed to predict the increment of the stand characteristics: quadratic mean diameter (QMD), basal area (BA) and stand density index (SDI). After analyzing the residuals for these three equations, the developers decided not to include the SDI growth equation in the model.

The purpose for modeling these three characteristics was to predict changes in QMD, BA and trees per hectare (TPH). The models were fit on data grouped by species association using non-linear regression. For example, the equation for quadratic mean diameter increment is:

$$d.QMD = [P\_QMD(i+1) - P\_QMD(i)] + FCONV * [QMD(i) - P\_QMD(i)] \qquad (2.2)$$

Where:

$P\_QMD(i) = Y1 * [(1 - \exp(-B*i))/(1-\exp(-B*50)] ** Gamma$ – yield equation (2.2a)

i = total age

FCONV = Min (g1 + g2*log(Age), 0)

Y1, B, Gamma, g1, g2 = coefficients

d.QMD = predicted annual change in quadratic mean diameter

P_QMD(i) = predicted quadratic mean diameter at age i

Equation (2.2) was used to model the annual increment of the quadratic mean diameter. The first part of the equation represents the difference between two successive predictions of the yield equation (2.2a). The initial values of the stand characteristics may be different from the values predicted by the yield equation. The last part of the growth equations, that contains the term FCONV, has the role of slowly adjusting the initial different values of the stand characteristics towards normality represented by the yield equation (Figure 2.1). If the initial "actual values" are above or below predictions, the last part of the equation has the role of lowering or increasing the predictions so as to approach the values of the yield equation (Dendron and Flewelling, 1995b).

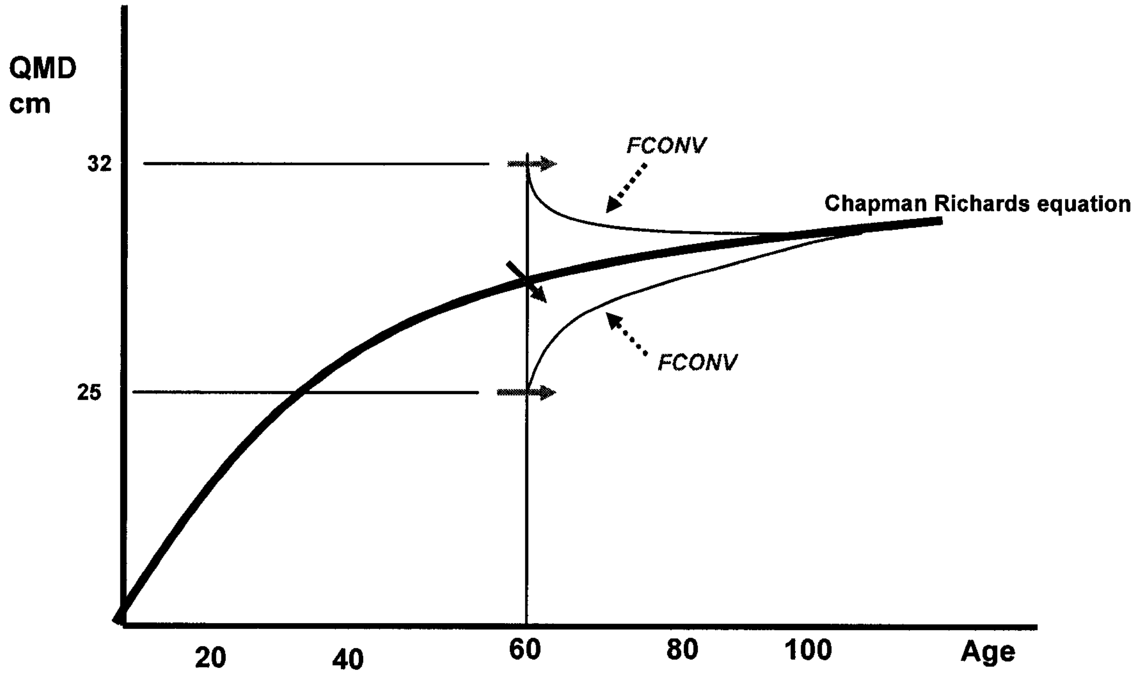

Figure 2.1: Quadratic mean diameter yield curve for white spruce – black spruce species association; the term FCONV is used to adjust downwards or upwards the projected stand basal area and gradually make it converge towards the yield curve.

Yield equations were constructed as "Normal", yield curves describing fully-stocked stands unaffected by biotic or abiotic events (windthrow, insects, disease) for each species association. The main independent variable was total age of the site species and in the case of aspen, top height was used. Other independent variables of interest were site index and stratum. Inconsistent data collection criteria over all years for smaller trees lead to imposing a minimum threshold of 9.05 cm in diameter at breast height (DBH) for trees used to fit the model. The equations were fit using non-linear regression.

Several yield equations were tested. The yield equation chosen for quadratic mean diameter was a parameterized Chapman Richards equation (2.3). Similar yield equations were developed for basal area and stand density index and were embedded in the construction of BA and SDI growth equations (Dendron and Flewelling, 1995b).

$$QMD = 9.05 + Y1 * [(1 - exp(-B*Age))/(1-exp(-B*50)] ** Gamma, \qquad (2.3)$$

Where:

QMD = quadratic mean diameter

B, Y1, Gamma = coefficients

Age = total age

The basal area yield curve does not vary with site index, only the quadratic mean diameter yield curve varies with the site index. These two sub-models were fit for each species association. The equations were programmed in FORTRAN and the coefficients embedded in the code.

The model also uses equations for top height and for calculating volume by species based on the same principal, a growth equation based on a yield equation that produces the annual increments. If no information is available from the inputs then the yield equation is used to determine initial conditions.

2.2.3 Mixedwood Growth Model (MGM)

MGM 2005 is a distance-independent, individual tree growth model created at the University of Alberta (Bokalo, Titus and Stadt, 2005). The data used for its construction were the Alberta permanent sample plots and other data.

The model simulates individual tree growth of four species: white spruce, trembling aspen, lodgepole pine, and black spruce. The other species are modeled as one of these four species. It should be noted that for this study, jack pine was modeled as lodgepole pine.

The model is based on empirical growth relations fitted using non-linear regression. The model embeds in its structure two sub-models, a juvenile growth model for seedlings (trees smaller than 1.3m) and saplings (trees with diameter at breast height lower than 4.0 cm), and a mature tree growth model. For each of the sub-models, relationships were developed for height and diameter increment, mortality and ingress.

Following the crop plan defined by the user, the main output of the model is a tree list with their characteristics at the end of the growth projection. The model also provides a series of stand characteristics (basal area, quadratic mean diameter, volume, density etc.), graphs, charts and summary tables with stand overall characteristics by conifer and deciduous groups. These are calculated using the individual tree characteristics.

Regional variants were developed for the sixteen Eco-regions in Alberta and two biogeoclimatic zones in British Columbia. Regional variants allow the use of regional species codes, site index curves and tree volume estimation equations. For Saskatchewan, provincial site index curves and provincial taper equations were used.

2.2.3.1 Modeling Framework

The model is composed of four Excel workbooks MGM.xls, MGM Crop Plans.xls, MGM Stands.xls, and MGM Records.xls. The MGM.xls is the main workbook of the model. It has several worksheets embedded in its structure. The MGM CropPlan.xls workbook is used to keep previous crop plans created in MGM.xls. MGM Records.xls is used to store the results from the Record worksheet and MGM Stands.xls is used to keep copies of stand individual tree lists that will be used as starting points for the crop plan scenario or to store interim and final tree list created during projections.

The simulation program is the "Crop Plan", which consists of a series of "Events". The events determine the source and characteristics of the stand, the growth schedule and all the other processes. The Establish event is the one that controls the input data, the way the tree list is created. Other events defined by the developer are: grow, harvest, harvest all, thin, record stand, regeneration, and loss.

The model starts its predictions from an initial tree list constructed based on the input data. This tree list can be grown through different scenarios defined in the crop plan using the juvenile and mature sub-models. The establishment of the stand with MGM can be done in several ways: using real tree data, simulating trees greater than 1.3 m in height and simulating regenerated trees. Once the stand is established and the list of trees is created, the stand is grown and manipulated according to the series of events described in the crop plan.

The model output provides growth information on both the individual trees and the stand. For the individual trees, records of trees' characteristics, such as diameter at breast height, height, breast height age, age, yearly height, and DBH increments can be obtained at different ages, specified by the user. The model also provides yield information for each species modeled, for the species groups, conifers and deciduous, as well as for the whole stand. The stand characteristics MGM predicts are quadratic mean diameter, average basal area, average height, density, average volume, top height.

2.2.3.2 Methodology Used for Constructing the Model

The model is based on the permanent sample plots from the Alberta PSP program. Some 900 permanent sample plots, with up to 5 re-measurements, located in mature timber stands were used for the model's construction. The plots were located in easily accessible fully-stocked stands. For the juvenile model several other datasets were used: Alberta Sustainable Resource Development Stand Dynamic System plots, Western Boreal Growth and Yield Association, Long Term Study plots (WESBOGY LTS) and regenerated permanent sample plots contributed by Alberta forest companies.

The model predicts growth based on individual tree height annual increment, individual diameter annual increment, mortality and in-growth relationships. The model has different relationships for predicting juvenile growth, for trees with DBH lower than 4.0 cm, and for predicting growth of mature trees, larger than 4.0 cm in DBH.

The juvenile model is a sub-model that applies only to seedlings (less then 1.3 m in height) and saplings (1.3 m in height to 3.9 cm in DBH). It has different relationships for modeling height and diameter increment for aspen, white spruce, lodgepole pine and black spruce. The model also contains relationships for the mortality of these four species. The growth relations were based on the analysis of several datasets: Alberta Sustainable Resource Development Stand Dynamic System plots, Western Boreal Long Term Study plots and regenerated permanent sample plots contributed by Alberta forest companies.

The mature model predicts height and diameter increment as well as mortality for all four species. The relationships for height increment are slightly different for aspen and white spruce mixtures as they include different terms to account for the basal area of deciduous and basal area of conifers.

The height increment is modeled as a function of the site index and of the position of the individual tree in the stand. It is assumed that the site index defines the height increment for the dominant and co-dominant trees, top height, but not necessarily the maximum height. The age of the tree is necessary to determine the height increment; if the tree age is not available, then the stand age is used. The diameter increment is modeled as a function of height increment. The survival probability for trees is estimated annually through a logistic regression having as independent variables DBH, BA, BA in larger trees, diameter increment, and species composition. The estimate of annual probability of survival is multiplied by the expansion factor to determine the number of surviving trees per hectare (Bokalo, Titus and Stadt, 2005).

2.3 Comparison of Actual versus Predicted Yields

2.3.1 Study Methodology

The objective of the study was to evaluate the predictions of the three growth models using a randomly selected sub-sample from the PSP database available at Saskatchewan Environmental – Forest Service. This database was chosen because the re-measurements allowed for comparison of actual growth to model predictions.

The data were first compiled to obtain the plot and stand characteristics needed for the plot selection process. The data were prepared as follows. First, the entire database was processed in order to classify the plots into species categories and then a sub-sample of plots was selected on which the analysis and comparisons focused.

From the selected plots, the data from the first measurement were used as the input in each model. The stand characteristics or the initial tree list, depending on the model, were used to project the stand forward in time. The last re-measurement was compared to the models' projection.

2.3.1.1 The Database

The dataset used in the study is a sub-sample of 140 permanent sample plots from the PSPs provided by SE. The first plots were established in 1949 and last measurements were made in 1994. The database included measurements made by Weyerhaeuser Company as part of their Forest Management Agreement (FMA) from 1994 to 2000. It should be noted that the only plots re-measured during this period of time were the PSPs within Weyerhaeuser FMA. The time length between the first and final re-measurement varied between 5 and 30 years.

The first plot measurements from 1949 to 1956 did not measure individual tree characteristics, i.e. the trees were tallied by DBH classes. This part of the database was not used for this study, such that all plots without individual tree measurements were removed from the database.

The trees with DBHs lower then 9.0 cm and all dead trees were deleted from the plot. This measure was taken because the trees smaller then 9.0 cm in DBH were not consistently available for all measurements over all plots. Additionally, if plot size was not available, the plot was also dropped from the dataset. The total number of plots used to randomly select the 140 plot sub-sample was 1122 permanent sample plots with the first measurement after 1956.

2.3.1.2 Data Compilation

In addition to the individual tree and plot data included within each PSP, several additional stand and plot characteristics were computed. For clarity, the definitions and calculations used for each characteristic are presented below.

Tree Factor based on plot size was computed for each tree so that plot characteristics (basal area, volume, density, etc.) could be extrapolated to per hectare values. Tree factor equals 10,000 m^2/plot area.

Basal area was calculated for each individual tree and was then summarized by species, plot and measurement time.

Quadratic mean diameter was inferred from basal area and the number of trees for each plot at a given measurement time.

Heights needed to be estimated for approximately 25% of the trees in the entire database. The equation used was a DBH-height Chapman – Richards equation calibrated for Saskatchewan. No further adjustment to the tree heights was performed.

Top height was calculated as the mean height of the 100 largest DBH trees per hectare (Husch et al., 1972). In this case, the first 6 or 8 largest trees by DBH, from each plot and at each measurement, were used to calculate top height. The number of trees used to calculate this parameter depended on the plot size.

Individual total tree volume was compiled using a Kozak variable exponent taper equation calibrated for Saskatchewan (Gal and Bella, 1994) and an algorithm presented by Huang (1994).

Total volume was calculated per tree, per plot and per hectare over all species or by species. The term "total volume" used throughout this chapter indicates that no merchantability criteria were applied. Volumes were computed at each measurement. Per hectare values were obtained using the tree factors based on plot size.

Age measurements were available for each plot. In most cases, ages were available at more than one measurement. Usually three dominant or co-dominant trees were cored to obtain age. The stand age was estimated as the mean age of the available individual age measurements. The first available age measurements were used to calculate the stand mean age. The trees cored for age and having a measured height were used as a basis for estimating site index.

Site index was calculated using a variable age site index equation from a draft unpublished report available in Saskatchewan (Cieszewski et al., 1993). The site index for each species in the plot was calculated by averaging the individual site index calculated for each individual tree with a height and an age measurement.

2.3.1.3 Selecting the sub – sample

The 140 plot sub-sample was distributed among four species: white spruce, trembling aspen, black spruce and jack pine. Two mixture types, pure and mixed stands were also considered. Pure plots were considered those plots where the basal area of one of the species of interest was greater than or equal to 80% of the total basal area of the plot. Mixed plots were considered those plots in which the basal area of the main species of interest was between 50% and 80% of the total basal area of the plot. From the entire available dataset, eight groups of plots were constructed, four pure and four mixed groups. There were insufficient data for the jack pine mixed stands so this group was dropped from the analysis. Each group consisted of 20 randomly selected plots stratified by inventory zones to represent the spatial distribution of the PSPs.

After analyzing and plotting the growth trends of this sub-sample, the results showed that around 20% of the randomly selected plots (cca 30 plots) showed unexplainable density and volume losses over time and thus unexplainable growth trajectories. These changes were not documented in the database and therefore could not be modeled since none of the growth models can capture loss events unless they are explicitly modeled. It was concluded that comparison of actual versus predicted growth for these plots did not offer any useful information concerning model performance. Plots with such events were replaced with other randomly selected PSPs.

Because some of the newly selected plots displayed the same unexplained decrease in density associated with high volume loss, it was decided to replace 19 of the last re-measurements, out of 140, with an earlier re-measurement of the plot. Five outliers were completely removed from the dataset, 3 plots in the mixed black spruce stratum, 1 plot in the pure black spruce stratum, and 1 plot in the pure aspen stratum.

2.3.2 Model Projections

The data from each initial PSP measurement was used as an input into each of the models to represent the starting stand conditions (*time1*). Subsequent actual re-measurements were compared graphically with the model's predictions at *time2, time3,* etc. Only the final re-measurement was used for the ±10% test and for the paired t-test. The difference in years between the initial and final re-measurement was considered the projection length.

The input requirements of each model were different; therefore in the data compilation phase it was necessary to compute all needed tree, plot and stand characteristics.

The provincial yield curves required canopy cover class, age of the stand, and stratum as inputs. The canopy cover class and stratum were read from the forest cover type associated with each plot and measurement. The PSP growth projections for this model were obtained by introducing into Equation (2.1) the subsequent age and canopy cover class.

For the Flewelling model, the input data consisted of the species association, as defined by the model's developer, the main species, the inventory zone, the site index and age. Age to breast height was assigned the default value predefined by the model for each species. Basal area, density and top height by species were also used as inputs.

MGM used the actual tree list from the initial measurement of each PSP as an input. Each tree was grown in height and diameter as a function of species, species site index for that plot and individual tree breast height age. A height – age equation calibrated for Saskatchewan was used to compute initial ages for all trees in the plot based on the site index of the plot species and the initial individual tree height.

2.3.3 Analysis

Five stand characteristics were analyzed in this study: total volume, basal area, density, top height and quadratic mean diameter. Not all models produced the necessary outputs and therefore not all comparisons were possible. The Provincial Yield Curves output was limited to only total volume. The Flewelling model did not output quadratic mean diameter.

The deviations between predicted and actual values were graphically evaluated for all stand characteristics at the last re-measurement. These deviations were plotted against the predicted values from each model as well as against the actual values from the plot re-measurements. These deviations were used to assess if any trends existed indicating some type of systematic bias. Ideally, the points should be evenly distributed above and below the zero line and the spread of the points around the zero line should be consistent over the range of predicted values.

Any trends in the deviations versus predicted values could indicate issues with the internal functions of the model. The deviations plotted against the actual values offer information about possible trends and biases in estimating actual stand characteristics. As previously discussed, some trajectory graphs (not shown) showed volume collapsing in certain plots, leading us to remove the plots with inexplicable behavior. Standardized trajectories were also created for all plots and characteristics by removing age (not shown).

Paired t-tests were done between the final predicted values and the final re-measured values for each variable of interest (volume, basal area, density, quadratic mean diameter and top height). For each variable in the output and every model, t-tests were performed with 20 pairs corresponding to the 20 selected plots by category (i.e. pure black spruce, mixed black spruce, etc.). The purpose was to determine if the differences between the actual measured values and the predicted values, at the end of the projection were significantly different for each of the models evaluated. A paired t-test is a statistical test that takes into consideration the variation around the mean to determine if actual versus predicted are significantly different. From a practical perspective predictions that are significantly different but are not too far from the actual may be acceptable, therefore a second test was done. This test determined whether the predictions were within ±10% of the actual data. All variables over all plots for the last re-measurement were submitted to the ±10% test. The results indicated how many of the predictions for each of the model ranged within ±10% of the actual values.

2.4 Results

In this section, deviation plots by species group and by stand characteristic will be presented. The results from the paired t-tests and the ±10% tests will also be presented for all three models.

2.4.1 The Provincial Yield Curves

The only output provided by the Provincial Yield Curves is total volume (m^3/ha). Volume deviations showed clearly that the model was under predicting the growth of permanent sample plots regardless of the species association or category from which the plots were selected. When the deviations were plotted against the actual values they presented a clear decreasing trend with the increase in actual volume (Appendix I.1). The model was under predicting growth for plots with medium to high volumes.

The results of the paired t-test showed that over all species associations, all predicted volumes were significantly different than the actual volumes (Table 2.2). The same poor correspondence between the predicted and actual volumes was apparent from the results of the ±10% test where only 5 of the volume predictions out of 135 were within ±10% (Table 2.2).

When all species were combined, the model was under predicting growth. The plots had their volumes under predicted with a range between 0 and 300 m^3, regardless of the species association. The under-estimating trend was apparent in all the deviation plots and in all growth trajectories (Appendix I.1). The trend of the actual data paralleled the trend of predictions (Appendix I.2).

2.4.2 Flewelling Model Results

The Flewelling model performance for plot volume and basal area was best across all species. The overall volume, basal area and top height deviations plotted against the predicted values did not show any particular trend. The range of deviations was narrow and the points were evenly distributed below and above the zero line (Appendix I.3). The density deviations are more scattered with a large range between the extreme values (Appendix I.3). The deviations span the predicted range showing that the model had no internal bias.

When the deviations were plotted against the actual values (Appendix I.4), a decreasing trend was seen as actual values increased. The trend appeared in volume, basal area, top height and density. Thus the model tended to increasingly under predict stand characteristics as the actual values increased (Appendix I.4). This trend was most obvious in the case of pure and mixed aspen plots. The model under-predicted re-measured values for basal area, volume and top height, with the range of under-prediction increasing with the increase of actual values.

The paired t-test results show that for each of the stand characteristics, total volume, basal area, density and top height, the predicted values were not significantly different than the actual values in four out of seven cases (57%) by species category. Pure and mixed aspen plots consistently showed results that were significantly different, for all characteristics (Table 2.3). The mean differences were mainly negative suggesting a slight under predictive tendency for the model.

The ±10% test shows that 77 out of 135 (57%) of the predicted volumes are within ±10% of the actual volumes, while basal area showed 108 out of 135 (80%). The density was predicted within the ±10% range 83 out of 135 (61%), while predicted top height was within the ±10% range 105 out of 135 (78%) (Table 2.4). Height and basal area were the best predicted characteristic, followed by density and volume.

The model performed best for pure and mixed white spruce, followed by mixed and pure black spruce as well as pure jack pine. Both ten percent test and the t-test show aspen stands among the poorest predicted stands. These under predictive trends were also supported by the deviations plots by species association (Appendix II).

2.4.1 Mixedwood Growth Model (MGM)

In general, MGM 2005A over predicted volume, basal area and quadratic mean diameter across all species. The deviations for volume, basal area and quadratic mean diameter plotted against the predicted values were mainly above zero showing a slight increase with the increase in predicted values. The model showed no particular bias in estimating the stand characteristics (Appendix I.5). The deviations for top height were not assessed since MGM calculated top height for each species group while plot top height was calculated for all species together. The density deviations had a small scatter around the zero line and were evenly distributed below and above zero (Appendix I.5).

When the deviations were plotted against the actual values (Appendix I.6) the number of the deviations above and below the zero line was maintained. The overall volume, basal area, and quadratic mean diameter were over predicted by the model with no visible trend. Density deviations showed a decrease in the predictions with the increase of the actual density. The over predicting trends were observed for all species groups.

The paired t-tests show that three out of seven categories had predicted volumes that were not significantly different from the actual values; one category out of seven had predicted basal area and quadratic mean diameter not significantly different from the actual values, while five out of seven categories had predicted densities not significantly different from the actual values (Table 2.5). The mean differences are positive for almost all species and characteristics, the only negative values are for density, suggesting the over predictive tendency of the model.

The results of ±10% test show that 62 out of 135 (46%) of the predicted volume 64 out of 135 (47%) of the predicted basal area, 94 out of 135 (70%) of the predicted densities and 109 out of 135 (81%) of the quadratic mean diameter are within ±10% of the actual values (Table 2.6).

The same over predicting trend across all variables and species was also visible in the deviations by species association. The deviations for all characteristics were mainly concentrated above the zero line with no specific trends (Appendix II).

2.5 Discussion

2.5.1 Provincial Yield Curves

2.5.1.1 Limitations

The limitations of the model can be divided in two categories, one imposed by the dataset and equations used to represent the relationship and the other imposed by the model's developers.

The 3P Sampling Program was meant to estimate volumes and not to be used as a database for yield curve development, such that the plot distribution across space and age classes was not fit for the construction of yield curves, as the plots did not randomly cover all possible forest and age conditions (Golder, 2001). Other factors that were inconsistent with the development of a yield curve were age (which was not always collected), and plot location biased towards accessible locations (Golder, 2001).

Data were also not stratified according to site index and the yield curves did not differentiate between productivity classes. The yield model was fit on un-stratified age class means calculated with a variable number of plots, leading to different degrees of precision for the estimates. R^2 values for the fitted curves varied between 0.23 and 0.90. The number of plots used in fitting the curves varied between 63 and 1200. The method used for curve development, fitting an equation to the means, inflated R^2.

Developers assumed that a deciduous stand, defined according to the presented criteria, would remain a deciduous stand throughout its life, not changing its species composition. Based on this assumption, young mixed stands and old mixed stands were amalgamated together in the same stratum. There is a strong likelihood that these old stands, whose history is unknown, might have had different species associations in younger stages.

The form of the curve leads to uncertainty in volume predictions over the age of 120 years (Golder, 2001). The form of the curve shows a decrease in the total volume after 120 years that does not always correspond to the biological expectations, resulting in less confidence in volume predictions above this age. This is particularly true for pure spruce stands that maintain high yields past 120 years.

Provincial Yield Curves output is limited because the model was developed to predict yield for a stand of a certain age, species composition and canopy cover. The yield curves predict merchantable volume and volume by species group for a stand using as input variables age, inventory zone, canopy cover class, and species association.

2.5.1.2 Discussion

Our results show that the model under-predicted yield of the permanent sample plots across all species groups. The shape of the deviations, visible in the deviation distribution, showed a clear decreasing trend with the increase of actual volume. Some uncertainties related to the model's inputs may have also played a role in the prediction. The stratum and canopy cover were two variables determined based on the "map type call". In some cases the plot's species distribution was in disaccord with the map type call. Attempts had been made to make better estimates of canopy cover from stem count conversion tables provided by Timberline Forestry Consultants, but the results were inconclusive.

Additionally, the age calculated as the mean from three individual trees was considered the stand age. In some cases, the plot DBH distribution indicated an uneven-aged structure. Under these conditions, it is unlikely that the age of three dominant trees characterized the age of the entire plot.

As previously presented, the strength of the equations used to predict yield for the seven groups varies between 0.23 and 0.9 from one group to another suggesting that not all the species groups are predicted with the same accuracy. The model also does not adjust yield for site productivity; canopy cover is the only variable used to account for stocking differences. This leads to modeling the average productivity of the dataset without being able to adjust the yield curves to actual plot productivity. Although the inputs affected the performance, they were not the main reason for the differences.

There are two reasons why the comparison between the yield curve model and the individual PSPs produced such large differences. The first reason is related to the yield difference between a TSP and a PSP. A permanent sample plot was thought to sample the "Normal" stand conditions, unaffected by biotic (insects, disease) and abiotic factors (windthrows), in fully stocked portions of the stand. The PSPs were therefore biased towards fully stocked accessible stands. On the other hand TSPs provide a measure of the actual yield in a stratum at the landscape level. The objective for the temporary sample plots is to acquire information about the mean stratum yield for each age class. This results in differences coming from the design of the two sampling procedures; the PSPs sample the fully stocked portion of the stratum, while the TSPs sample the entire stratum.

The second reason is related to the scale difference between the yield curve predicting landscape mean stratum yield and a permanent sample plot representing a small portion (cca. 1000 m^2) of fully stocked stand, unaffected by abiotic and biotic events. Therefore, when a PSP is projected using a yield curve, the plot volume is assigned the mean stratum yield corresponding to the PSP age, canopy cover, and species association. The scale difference results from the two terms of the comparison: the predicted yield represents the mean stratum yield while the actual yield represents the yield in a small fully stocked plot.

2.5.2 Flewelling Model

2.5.2.1 Limitations

PSP selection for model development was due to the need of successive re-measurements of the same plot. The limitations of the model are linked to the dataset the growth model is based on and to the methodology used by the developers. A limitation for the final user is linked to the range of information the model offers as well as the range of species associations it can be applied to.

Limitations Imposed by the Dataset

The data do not proportionally cover all forest types and all inventory zones. Only six species associations from four inventory zones had sufficient data to be included in the model. Plots with insufficient data to construct height-diameter equations were discarded (Dendron and Flewelling, 1995b).

The methodology for collecting data was different among the participating companies and it also changed over time. Between 1949 and 1956, the trees were tallied by diameter class. In later measurements the in-growth and mortality were not consistently sampled. The units of measurement were also not consistent, at first imperial units were used and then metric units. This procedure shifted the tagging limits and the breast height. In addition, because of missing breast height age, site curves could not be rigorously tested.

Most of the PSPs were established in well stocked stands, therefore low density conditions are not commonly represented. This leads to a greater bias when projecting low density stands compared to fully stocked stands (Dendron and Flewelling, 1995b). There is also no mechanism in the model that takes into consideration the difference between low density stands and fully stocked stands.

The existing data and their patterns resulted in the modeling process being restricted to only six species associations and five species groups. These species groups are strictly linked to the available data and do not reflect a choice of the developers.

Limitations Imposed by the Method Used for Model Development

The model cannot predict juvenile growth, i.e. trees lower than 1.3 m in height or trees with ages lower than breast height age by species. The model is able to predict growth only if stand total age is equal or greater than the breast height age of the species. The breast height age is a predefined input for all species as well as merchantability criteria, although stands might take different periods of time to reach breast height age. Volume is always computed with the same set of predefined merchantability standards. The model is rigid and it is not capable of adapting to different stand conditions.

Other limitations occur in the accuracy of the model for predictions in stands that go through break up, since this stage is not directly predicted. The model also does not predict succession, making long term projections difficult (Dendron and Flewelling, 1995b).

Limitations Imposed by the Output

This model offers a narrow range of information as output data. The model predicts basal area, trees per hectare, top height, volume (gross and merchantable). The predictions are for total stand and for species groups. The user has no control over the standards embedded within the model. The distribution of stand characteristics (quadratic mean diameter, basal area, volume) by component species, in mixed stands, is done internally within the model.

The model was intended as a first attempt at developing a growth model for Saskatchewan. Due to its limitations it was not used by the forest companies or SE. An improved version, from 1997, was in use by Weyerhaeuser, but it was not available for this study.

2.5.2.2 Discussion

Our results show that all plot characteristics, volume, basal area, density, and top height were predicted well by the model. Some differences were related to the quality of inputs, stand age in particular. The model grows a stand based on the assumption that the age represents the actual stage of development and that the stand is even-aged. However, DBH structure in some plots did not conform to this condition. The DBH structure was closer to uneven-aged (histograms not shown) with several cohorts of different sizes. Since age was representative for only one cohort, the projections underestimated or overestimated the actual re-measurements, depending on the growth rates of the other cohorts.

The best predictions were for pure and mixed white spruce, mixed black spruce and pure jack pine species associations. For pure and mixed trembling aspen as well as for pure black spruce species associations, the model is under predicting growth, especially basal area. This trend is associated with a DBH structure closer to uneven-aged stands and with a mean age that has little meaning in such cases.

The good quality of predictions is explained by the model robustness. The Flewelling model uses basal area and quadratic mean diameter as the primary drivers of growth. Basal area is a very stable and reliable variable, explaining the high quality of the predictions. In the model's construction, basal area does not vary with site index, there is only one basal area yield model for each species association, and therefore the model is less susceptible to erroneous site index. Volume variation due to site productivity is only modeled through the increment of quadratic mean diameter and the top height. One of the reasons site index may have been under-emphasized was that calculated site indices were very inconsistent over time. Minimizing the influence of site index is one of this model's strengths in making sound growth predictions of PSPs, but it also limits the ability to be sensitive to productivity differences.

As a consequence of this modeling approach, variations in age and site index have only a small influence on the predictions, such that, the main trajectory for growth is drawn by the basal area and quadratic mean diameter sub-models. The effects of site index on quadratic mean diameter are small and cannot offset the dominance of the basal area trajectory in predicting yield.

In contrast to the predictive performance on PSPs, this modeling approach also has several drawbacks. The model has an interesting ability to "increase density" as seen in some of the results. This characteristic is related to the model structure and internal processes. It is unique because the model does not directly predict ingress nor does it have an explicit mortality function. The only dependent variables modeled are basal area, quadratic mean diameter, and top height. Density is calculated from these two variables. In some cases the density of the stand is internally increased to accommodate the relationship between the quadratic mean diameter and basal area.

Another drawback related to the modeling approach is that it is not possible to model poorly stocked stands or over stocked stands for longer periods of time (Dendron and Flewelling, 1995b). The model will always adjust or force the growth/yield to the yield curve, which represents the average PSPs growth and yield upon which they were constructed (Dendron and Flewelling, 1995b). The model is very good at predicting the average PSP growth, but it cannot be changed or varied to produce different types of growth. The reliability of the model also decreases when it is used to predict uneven aged structures since the model cannot differentiate stand structure explicitly. This is because all cohorts are averaged and modeled together, and then volume is inferred from the total volume predicted. This procedure does not take into account the dimensions or range of the initial DBHs that form the initial basal area.

As a consequence of this modeling approach, the model has no ability to respond to changes in stand structure. The model loses the linkage to the individual trees and the structure of the PSP that are being projected. This also limits one's ability to draw conclusions on how stand structure has changed over time. For example, thinning for release would not result in a release, but in the long run, predictions would be adjusted to return to the "mean" yield of the PSPs.

Model outputs are also limited. For example, quadratic mean diameter could not be evaluated because it was not an output option, even though it is an integral part of the model itself. The computer model is also extremely primitive and inflexible in its coding and user interface even though the internal functions are sound. Creating the projections can be a laborious task, because the input data have to be prepared for each run.

It should be noted that the sub-sample of PSP data used in this test was drawn from the same population used to fit the model's equations, and therefore this evaluation cannot be considered a true validation on an independent dataset. Although this study should not be considered a true validation, the results are still considered a good evaluation of how the model performs against re-measured data.

2.5.3 Mixedwood Growth Model

2.5.3.1 Limitations

The limitations for MGM can be separated, as for the other models, into two categories. Limitations imposed by the dataset and the relationships used and limitations imposed by the outputs. The first category refers to the restrictions imposed by the developers on the data they are using and the relationships they can find within these datasets. The second category refers to the available outputs a model provides at the end of projection.

Limitations Due to the Dataset

The number of PSPs used in the model's development is not sufficient to characterize the entire boreal forest in Alberta. The growth relationships are based on datasets from Alberta. These relations might not be the same for all the area the model might be applied to, for example Saskatchewan.

Most of the plots used for MGM development are in mature stands, older than 45 years. There was a serious lack of data for mid-rotation stands aged between 20 and

45 years. The dataset used in the construction of the juvenile model came from young post-harvest stands. The mature model is based on mature PSPs of post-fire origin.

The permanent sample plots were located in well stocked stands, "Normal" stands, therefore the predicted volumes are higher than the actual landscape level volumes so that the stand MGM is growing is a fully stocked stand, similar in structure to a PSP.

Limitations Imposed by the Developers

The series of events and the possibilities of editing them can also be considered as limited. Windthrow, insects or other pests are not explicitly modeled, although they can be accounted for through "Loss" events. The four species grouping used by MGM (white spruce, trembling aspen, lodgepole pine and black spruce) is also a limitation imposed by the developers since other species are modeled as one of these four.

These limitations were imposed by the developers due to data and other limitations. However, the range of information MGM can process, as well as the range of outputs and predictions is far greater than in the case of the other two models. Overall, the degree of complexity of the models presented, as well as the amount of work used to develop them, increases from the Provincial Yield Curves through to MGM.

2.5.3.2 Discussion

The factors that determine the quality of the MGM predictions are strongly related to the quality of the input data as well as to the internal functions and processes embedded within MGM. As a distance independent individual tree model, the input data requirements are very high. If inputs are erroneous, missing or are inferred from other variables, the performance of the model can be reduced. MGM produces a detailed tree list from which many different outputs can be generated such as diameter distributions and height distributions which could be used to analyze piece size for example. MGM also permits users to schedule and perform actions on the tree list such as harvests and thinning to simulate treatments.

Overall the model is over predicting volume, basal area and quadratic mean diameter, with larger over predictions in the case of white spruce and jack pine. Density is predicted better for all species. The range of over predictions varies by species and by stand characteristic.

Over predictions appear to be related primarily to input data, mainly stand age and site index. There is also an effect due to possible differences in growth rates between provinces. MGM predicts individual tree growth and the results expressed on a per hectare basis are simply the summation of individual tree characteristics. The independent variables used to calculate height and diameter increment are species, site index, breast height age and a measure of competition that takes into account the social position of the tree within the plot. The calibration of the model for Saskatchewan consisted of using the Saskatchewan site index curves and the Saskatchewan height – age equations. The height increment, diameter increment and mortality functions, used to calculate individual tree growth, are empirical equations based on PSP data from Alberta. As in Saskatchewan, Alberta's PSP are biased to fully stocked stands and are intended to represent the "Normal" conditions. However, differences between the two provinces were not scrutinized. There is a possibility that higher growth rates from Alberta could have been reflected in the over predictions.

Site index is a critical component in MGM as it is the foundation for determining height and diameter increment. Some of the PSPs used in the study did not have initial height and age measurements. The site index was calculated for each re-measurement, where data was available. However, for consistency, the first measurement was used as input for the plot projection. In many cases the site index represented only the dominant species, data for other species in the plot were not available. This leads to projecting individual trees on site index curves that were not determined based on field data, leading to possible erroneous results. At the same time, higher site indices determined greater growth rates for all trees in the plot. Erroneous productivity has a cumulative effect that increases with the projection length.

The growth rate is also influenced by the individual breast height age. Since plot mean age has little meaning when dealing with multi-cohort stands, a height – diameter equation was used to calculate the individual age as a function of site index and initial tree height. It is recognized that this process is somewhat circular but was far better than assuming all trees in a given plot had the same age. This improved estimates, but ideally, a measured age for each tree should be used.

Quadratic mean diameter is one variable that was consistently over predicted by MGM 2005 for all species. This is related to a potentially over-optimistic internal diameter increment function and problems with assigning correct breast height ages. The range of densities predicted by MGM was much narrower than the actual density of the PSPs. This indicates that many plots were affected by events that are outside the normal mortality that were predicted to occur in PSPs. Certainly, if the measurements were closer in time and different events that affected the stand were recorded, the model's predictions could have been adjusted by modifying the input data.

2.6 Conclusions

This study was not focused on comparing the models but rather comparing model predictions to actual growth trajectories of PSPs. The approaches taken for building these models were different, each being part of a different model category: yield curves, whole stand growth model and distance independent growth model.

The behavior of the Provincial Yield Curve model suggests that there is a great disparity between PSP yields and landscape level yields. This disparity is caused by the sampling biases associated with the TSP and PSP measurements and by the scale difference between the model predicting the average yield of the landscape and the PSP representing 1000 m^2 of a well stocked stand. It is clear from this chapter that the yield in a permanent sample plot and the landscape level mean yield are different.

The Flewelling model is robust and created so that it avoids problems with uncertainty concerning age and site index. The sample used to evaluate the model is not independent, it was used to fit the model's equations, which may in part explain the quality of the predictions. The drawbacks of the model are related to the limited geographical area and limited number of species associations where it can be used. The user interface and the output file are also difficult to use. The continuous adjustment of growth towards the yield curve also constitutes a drawback, since all predictions, no matter what the starting conditions are, will approach and be finally modeled on the PSP yield curve.

The Mixedwood Growth Model is susceptible to erroneous input data, mainly because the individual tree growth is linked to site index values and breast height age. These two variables were the most inconsistent in our sample. Breast height age data was not available for all the species in the plot. Sample tree heights were calculated using a provincially calibrated DBH – height equation. Furthermore individual breast height ages were assigned to each tree based on a height – age equation, since the DBH distribution in most of the plots suggested an inverse J-shaped curve characteristic to uneven-aged stands. Since MGM is the most data demanding model, a lot of the input data were by-products produced using the previous equations.

It is difficult to differentiate, under the presented conditions, how much of the MGM over-prediction is related to erroneous input data (initial height, breast height age or site index), internal functions of the model, or actual growth differences between Saskatchewan and Alberta PSPs.

The discrepancy between predictions of TSP based models and PSP based models apparent in this chapter suggests that PSPs in Saskatchewan were biased towards fully stocked stands. Since the same plot age was used as input in all models, the yield differences in the final predictions can be attributed largely to stocking and site productivity differences between TSPs and PSPs. The stocking differences at the stand level will be further investigated in Chapter 3 using a sample of AVI polygons.

Each model has its strengths and weaknesses, therefore users of any of these models must clearly understand the underlying assumptions, limitations and general behavior that are embedded in the model by design. It is difficult to formulate recommendations for the use of one model. It very much depends on the objectives of the user and on the degree of confidence required.

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Table 2.1: Canopy cover classes and their range in percentages based on aerial photographs

Designation for Canopy Cover Class	SE Designation for Canopy Cover	Range (%)
1	A	10%<=A<=30%
2	B	30%<B<=55%
3	C	55%<C<=80%
4	D	80%<D<=100%

Table 2.2: The results for paired t-test and the ±10% test for the Provincial Yield Curves by species association. The mean volume deviations are presented (m^3), shaded areas are significantly different ($\alpha = 0.05$). The ±10% test results present the number of predictions that were within ±10% of the actual values. Total number of not-significant is summarized.

Provincial Yield Curves	N	PAIRED T-TEST TVOL (m^3) (Mean)	±10 % TEST TVOL (N)
Sb mixed	17	-197.98	0
Sb pure	19	-141.95	0
Pj pure	20	-93.06	1
Aw mixed	20	-157.46	0
Aw pure	19	-111.08	3
Sw mixed	20	-126.67	1
Sw pure	20	-183.72	0
Total number of not-significant	135	0/7	5/135

Table 2.3: The results for paired t-test for the Flewelling model by species association. The mean volume deviations (m^3), mean basal area deviations (m^2), mean top height deviations (m), and mean density deviations (SPH) are presented, shaded areas are significantly different ($\alpha = 0.05$). Total number of not-significant is summarized.

FLEWELLING	N	TVOL (m^3) (mean)	BA (m^2) (mean)	TOPHT (m) (mean)	DENSITY (sph) (mean)
Sb mixed	17	2.98	-0.30	-0.05	-48
Sb pure	19	-20.86	-1.62	-0.49	-61
Pj pure	20	3.59	-0.80	0.48	-76
Aw mixed	20	-34.30	-2.38	-2.30	-73
Aw pure	19	-24.70	-2.43	-1.02	-169
Sw mixed	20	-3.62	-0.18	-0.85	-6
Sw pure	20	-4.95	-1.19	0.08	-26
Total number of not-significant	135	4/7	4/7	4/7	4/7

Table 2.4: The results for the ±10% test for the Flewelling model by species association. The ±10% test results present the number of predictions that were within ±10% of actual for total volume, basal area, top height, and density. Total number of not-significant is summarized.

FLEWELLING	N	TVOL (N)	BA (N)	TOPHT (N)	DENSITY (N)
Sb mixed	17	11	14	15	12
Sb pure	19	8	16	17	15
Pj pure	20	13	17	16	16
Aw mixed	20	7	15	10	8
Aw pure	19	9	11	14	6
Sw mixed	20	14	18	14	13
Sw pure	20	15	17	19	13
Total number of not-significant	135	77/135	108/135	105/135	83/135

Table 2.5: The results for paired t-test for MGM by species association. The mean volume deviations (m^3), mean basal area deviations (m^2), mean quadratic diameter deviations (cm), and mean density deviations (SPH) are presented, shaded areas are significantly different ($\alpha = 0.05$). Total number of not-significant is summarized.

MGM	N	TVOL (m^3) (mean)	BA (m^2) (mean)	QMD (cm) (mean)	DENSITY (sph) (mean)
Sb mixed	17	19.84	2.87	0.5	-14
Sb pure	19	0.90	1.20	0.6	-112
Pj pure	20	37.39	2.97	1.2	-77
Aw mixed	20	10.67	3.59	0.5	32
Aw pure	19	39.56	5.48	1.4	-44
Sw mixed	20	42.10	5.80	1.3	25
Sw pure	20	52.46	5.14	1.1	26
Total number of not-significant	135	3/7	1/7	1/7	5/7

Table 2.6: The results for the ±10% test for MGM by species association. The ±10% test results present the number of predictions that were within ±10% for total volume, basal area, quadratic mean diameter, and density. Total number of not-significant is summarized.

MGM	N	TVOL (N)	BA (N)	QMD (N)	DENSITY (sph)
Sb mixed	17	9	8	17	12
Sb pure	19	15	14	17	16
Pj pure	20	7	11	14	15
Aw mixed	20	10	8	17	13
Aw pure	19	7	5	10	10
Sw mixed	20	9	9	17	15
Sw pure	20	5	9	17	13
Total number of not-significant	135	62/135	64/135	109/135	94/135

Chapter 3. Understanding Volume Loss Factors for the Mixedwood Growth Model

3.1 Introduction

Growth and yield models are an important part of the management and planning strategy in Alberta. Under the new Alternative Regeneration Standards (SRD, 2006) in Alberta, companies are allowed to use growth models to construct yield curves for Timber Supply Analysis in those instances for which data are unavailable. One example is the rotation length growth projection of post harvest stands, where the oldest post harvest stands do not exceed 40 years.

Growth and yield models simulate forest dynamics (i.e. forest growth, mortality, regeneration, and associated structural and successional changes in the stand) over time (Peng, 2000). Growth and yield models are currently used to help forest managers make decisions because of their ability to help in predicting future yield, exploring management alternatives and silvicultural options (Peng, 2000), and updating forest inventories (Bokalo, 1994). A wide range of models have been developed for different purposes (yield predictions, stand simulation, research) incorporating different levels of mathematical complexity (Peng, 2000). All models are simplifications of complex systems and are based on a set of assumptions and simplifications of the real dynamics that permit predictions. Some examples of growth models types are whole stand models (Growth and Yield Projection System), distance-independent individual tree models (MGM) or distance-dependent individual tree models (Tree and Stand Simulator).

However, when permanent sample plot (PSP) based models are used to predict landscape level yields, differences between the model predictions and actual landscape level yields have been reported.

The Mixedwood Growth Model (MGM) (Bokalo, Stadt and Titus, 2005) is an individual tree, distance-independent growth model developed for the boreal forest. The mature stand model relationships are based primarily on Alberta Permanent Sample Plot (PSPs) data, while the juvenile stand relationships come from post harvest data. One would expect that the model would be able to accurately predict growth in the mature natural stands, given that this was the data upon which the model was built. However, as shown in the previous chapter, MGM tends to over predict volume when compared to mean landscape level yields. The main reason is that the model was based on PSPs that were biased towards better stocked stands less affected by disturbances (i.e. "Normal" stands). The over prediction is caused by not accounting in the model for biotic and abiotic factors that reduce forest yield at the landscape level.

The Timber Interpolation Program Stand Yields (TIPSY) model developed by the Ministry of Forests in British Columbia (BC Ministry of Forests, 1998a) is one example of a model which overestimates yield. Operational Adjustment Factors (OAF) are used to adjust the model's predictions downwards to fall in line with expected landscape yields. Because TIPSY is exclusively used in projecting young, single species stands starting from an initial density, on a pre-defined productivity level (site index), the adjustment factors are used to calculate the initial input density in TIPSY as well as to adjust the model's yield prediction at harvest (BC Ministry of Forests, 1998a). TIPSY projections are currently used as yield curves throughout British Columbia.

The British Columbia Ministry of Forests identified two Operational Adjustment Factors, OAF1 and OAF2, in relation to the type of volume loss. The first operational adjustment factor, OAF1, represents un-stocked areas or gaps and is assumed to have a constant impact on the stand growth throughout its entire life (Timberline, 2001). The second operational adjustment factor, OAF2, accounted for the yield loss produced by biotic or abiotic factors (BC Ministry of Forests, 1998a) and was considered to increase throughout the entire life of the stand (Timberline, 2001), assuming older stands became more susceptible to insects and disease.

The assumption under which the operational adjustment factors operate in BC is that the only quantifiable difference between the model's predictions and the landscape yield is an area loss (un-stocked area) (BC Ministry of Forests, 1998b). A survey method is used to estimate the area in gaps to be removed from the stand projection based on a systematic sample of a fixed number of plots. This method is specifically designed for pure young stands. The plot, 3.6 m or 2.7 m in radius depending on the species, was considered to map a permanent gap if there was no acceptable tree (unhealthy, too small, not an accepted species) within the plot borders (BC Ministry of

Forests, 1998b).The survey was placed in young pure stands with complete and stable establishment (BC Ministry of Forests, 1998b) and the results of the survey were used to determine the OAF1 input for TIPSY and the initial stand density. A pre-determined value of 15% can be used to adjust the yield downwards when no field data are available.

A second example of a growth model over-estimating the landscape level yield is presented in Chapter 2. The model comparison showed a yield discrepancy between the models built using PSP data, Mixedwood Growth Model (Bokalo, Stadt and Titus, 2005) and Flewelling model (Dendron and Flewelling, 1995), and models built on a large random sample of temporary sample plots (TSPs), such as Provincial Yield Curves (Golder, 2001).

There are several reasons why there are differences between model predictions and landscape level yield values. Firstly, the data used to build relationships within growth models are limited and do not represent the population as a whole. Growth models require repeated measurements of the same plot in order to capture the growth rates, patterns, and mortality of individual trees. Permanent sample plots are commonly used to develop these relationships. These permanent sample plots are not usually random samples from the population, but rather selective samples of areas of interest (Bokalo, 1994). As a consequence PSPs in Alberta were biased towards better stocked post-fire origin stands. The plot locations were biased towards stands with "Normal" development, avoiding stochastic events, biotic and abiotic factors (windthrow, insects, disease).

These events on the landscape create gaps and lower stocked areas thus lowering the overall average productivity of an area. MacIsaac et al. (2006) found that post harvest stands presented several types of gaps: persistent gaps, harvest gaps, new gaps and wet area post harvest gaps. The area in gaps larger than $100m^2$ was up to 29% of the postharvest stand 12 years after harvest. Eriksson (1967) found that PSPs in Sweden tended to overestimate total stand yields by 15%. Cumming et al. (2000) found up to 16% of the stand area in gaps in pure aspen natural stands and that the stand area in gaps was increasing with age. Therefore the models built on PSPs tend to produce results similar to that of the "Normal" fully stocked stands that they were built upon, and do not reflect the landscape average.

The second reason that contributes to the overestimation of yield by models is related to the modeling assumptions. MGM, for example, grows an individual tree list using individual species, age, and site index. Since the model is distance independent, estimates of competition are not based on the actual neighborhood surrounding the tree, but calculated based on the average social position of the individual in the tree list (smallest tree is the most affected). This often conflicts with the "true" spatial distribution of the individual trees and competition mechanisms at the landscape level where one is likely to find some trees which are competition free. Additionally, MGM ignores tree clusters and assumes trees are evenly distributed over the area.

The third reason models tend to overestimate yield is due to a failure to meet modeling assumptions, when model predictions are applied to the landscape level to characterize larger areas formed by grouping similar stands.

Because PSPs tend to be fully stocked and uniformly spaced over the area, they tend to adhere to the traditional definition of a biological stand as "a contiguous group of trees sufficiently uniform in species composition, age-class distribution, structure, and growing on a site of sufficiently uniform quality, to be distinguished from surrounding stands and managed as a single unit" (Helms, 1998; Robertson, 1971). This definition corresponds well with the modeling assumption within MGM.

However, at the landscape level a forest inventory is usually in place to delineate stands based on a set of criteria that do not correspond well to this "biological" definition of a stand and thus invalidate assumptions when modeling with MGM. For example, in Alberta, the inventory polygons to which the model predictions are applied, are delineated based on aerial photographs and criteria outlined in Alberta Vegetation Inventory standards manual (AEP, 1994).

In Alberta the forest landscape is represented by Alberta Vegetation Inventory (AVI) polygons which use similar map type calls (canopy cover class, species composition, polygon height, and origin) to delineate the landscape. These polygons are often considered homogeneous, but in reality are heterogeneous entities formed from several differently stocked fragments. It is believed that there is a strong relationship between stocking quantified by canopy cover and volume for a series of similarly typed polygons (similar map type calls). By integrating this relationship at the polygon level a fragmentation index could be developed linking polygon mean volume to number of fragments and their stocking range expressed as canopy cover range. This index would constitute the Volume Loss Factor needed to adjust downwards "Normal" MGM predictions for heterogeneous polygons.

AVI delineates polygons based on canopy cover, species composition and stand height (AEP, 1994). There are four canopy cover classes in the Alberta Inventory Vegetation (AEP, 1994). Canopy cover refers to the proportion of forest floor covered by the vertical projection of tree crowns (Jennings at al., 1999). Stand (polygon) height is the average of the dominant and codominant trees of the leading species (AEP, 1994). Adjacent stands that are separated on the basis of height alone must have a difference equal to or greater than three meters (AEP, 1994). Species composition (maximum five) is based on the proportion of the canopy cover, in 10% units, represented by each individual species at the polygon level. The minimum area for delineating polygons is 2 ha, but under certain conditions (i.e. there is no occurrence of unproductive forest land, non-forest land, anthropogenic land, etc.) the minimum area increases up to 20 ha (AEP, 1994). The criteria become even more relaxed when these new minimum areas are delineated.

Additionally, AVI single story polygons are considered to be even-aged, stand age is determined based on the date of the last major fire in the region. The natural aspen dominated stands in the boreal forest were generally considered even-aged, having originated from massive fires and insect outbreaks (McCarthy, 2001). Betters and Woods (1981) describe aspen as a highly intolerant species usually growing in even-aged stands. McCarthy (2001) believes that contemporary forest management in many parts of the boreal forest is predicated on a scenario of even-aged forest dynamics which has in turn produced relatively simple even-aged silviculture and growth and yield modeling. Bergeron (2000) has reported that aspen stands can include multiple age classes.

Polygon variability is often larger than biological stand variability, although the terms stand and inventory polygon are often used synonymously. The differences come from the different levels of variability accepted in their definition. The criteria for delineating polygons do not refer to absolute values but rather to mean values for polygon characteristics (canopy cover, polygon height). Polygon variability is also increased by the photo interpreter's subjective call. When growth model predictions are applied to such polygons, yield discrepancies may arise.

To resolve MGM's yield over prediction all three presented reasons need to be addressed. However the first two, PSP database and modeling assumptions, are components of the model and would require a new, unbiased database of PSPs to address the first issue and an alteration of the assumptions the model is based upon to address the second.

One possible solution for the over prediction is to develop an index that would quantify the variability in stocking of the AVI polygons. Variability in stocking within a landscape is the major source of the over predictions. That is because the criteria for polygon delineation are not very rigorous, resulting in polygons, unlike biological stands, which are quite variable (heterogeneous). Polygons are actually a grouping of biological stands.

Since MGM assumes an even distribution of trees and it is based on "Normal" PSP data, we can assume that the yield curve produced by the model represents the higher end of the landscape volume. One way to connect this yield curve to match the yields in fragmented (heterogeneous) and partly stocked polygons is to develop a mechanism to classify polygons based on their degree of stocking heterogeneity. A Volume Loss Factor (VLF) would classify the polygons and link their heterogeneity (number of fragments and stocking range) to the yield (volume) differences. Yield differences can be quantified based on stocking differences in even-aged polygons with similar characteristics (species composition, top height, canopy cover range, etc.). The variable that quantifies stocking needs to be readily identifiable on the aerial photographs or already existing in AVI so that the relationship can be applied at the landscape level. Canopy cover is one variable which can be used to differentiate between differently stocked polygon fragments.

Canopy cover is the only variable expressed as a range in AVI. Canopy cover was traditionally used to construct stand volume tables because of its relation to stand volume per hectare (Avery, 1966). Canopy cover was applied in lieu of basal area or number of trees per hectare in yield table construction, as stand basal area and density could not be accurately determined on aerial photographs (Avery, 1966). The VLF development is similar to the development of stand volume table from aerial photographs for a small group of polygons with similar structure and species composition. Two approaches were used for aerial volume table development, one was based on integrating mean individual tree volume across area, while the other used stand characteristics to directly describe stand volume per unit area (Paine, 1979).

Canopy cover, together with top height and crown diameter, was a key variable in both approaches (Paine, 1979). Nyyssonen (1957) suggests that the addition of crown diameter was of little importance when percent canopy cover was used. Pope (1962) built stand volume tables for Douglas-fir using aerial photographs and tested different combinations from a series of nine variables including canopy cover, top height, their square, and all their potential interactions.

Avery (1958) used aerial canopy cover as a key variable in the development of composite volume tables for southern pine and hardwoods. In the process he determined the number of trees per unit of area by dividing the mean aerial canopy cover by the average tree crown area.

Gingrich and Meyer (1955) built stand tables for upland oak in Centre County, Pennsylvania. The area was represented by stands with a wide range of top heights and stocking. The authors found that two variables, field measured top height and aerial photo canopy cover, best explained volume variation for upland oak and used these variables to estimate stand volume. Using 93 0.2 acre plots (809 m^2), randomly distributed across the landscape and localized on 1:12,000 aerial photographs, the authors found two models that best described volume variation, both based on top height and canopy cover:

$$Y = b_1CC + b_2HT \qquad (a)$$

$$Y = b_1CC + b_2CC*HT/100 \qquad (b)$$

In the above equations Y is the dependent variable represented by merchantable volume (m^2), CC represents canopy cover (%) and HT is the top height (m) calculated with the three tallest trees in the plot (Gingrich and Meyer, 1955). Top height was measured in the field while canopy cover was estimated on the aerial photographs using a dot grid (Gingrich and Meyer, 1955). Model (b) was considered to better represent volume variation since it implies that, for a given stand height, stand volume is proportional to relative canopy cover. In contrast, equation (a) would imply that for a given increase in canopy cover, the corresponding increase in stand volume would be the same regardless of the height of the stand (Gingrich and Meyer, 1955). All these studies use canopy cover as a key variable in describing volume variation across the landscape.

The present study is focused on quantifying mean polygon volume variation across heterogeneously stocked polygons, but with the same stand characteristics. Since canopy cover was selected as the key variable to account for stocking differences, the first step in this process is to quantify the relationship between canopy cover and volume.

By reducing the population of interest to a small number of very similar polygons (similar polygon heights, species composition, and stocking range) and by stratifying the polygons based on 10% units of canopy cover, the relationship between volume and canopy cover should be emphasized. Since top height would become a constant across the polygons and strata, both models developed by Gingrich and Meyer (a and b) could be written as:

$$Y = b_0 + b_1CC \qquad (c)$$

A strong relationship between canopy cover and volume is expected in a population of polygons with similar characteristics. The relationship could be used in two ways. One way would be to directly adjust yield in individual fragments within polygons based on the slope of the relationship. The slope would quantify the rate of change of volume with canopy cover increase. A second approach would be to formulate an index to describe polygon heterogeneity. This index that quantifies stocking heterogeneity could be formulated using canopy cover. Based on the relationship between canopy cover and yield this index could then be calibrated as an estimate of VLF.

Since polygon heterogeneity is similar to landscape level forest fragmentation some of the fragmentation indices presented in the literature and referring to landscape fragmentation were adapted to the polygon level and used to characterize individual polygons. Forest fragmentation was defined as the process through which formerly large and continuous forests turn into a set of small and isolated patches (Haila, 1999). Some of the indices adapted from the landscape level to the polygon level are: number of patches (NP), mean patch size (MPS), largest patch index (LPI).

The first objective of the study was to assess the relationship between canopy cover, as a measure of stocking, and yield differences across strata of different canopy cover. A second objective was to investigate the relationship of volume to other stand characteristics such as top height, quadratic mean diameter, basal area, breast height age and site index as well as combinations of these explanatory variables. A third objective was to test the potential use of fragmentation indices in characterizing polygon heterogeneity and in describing mean polygon volume variation.

3.2 Methods

3.2.1 Study Overview

The general design involved identifying pure aspen and spruce dominated polygons (AVI) from two geographically separate locations in Alberta using existing AVI map type calls. From this pool, 12 pure aspen and 10 spruce dominated polygons, similar in structure (height, species composition, stand age, and canopy cover) were selected. The stand boundaries were then transposed onto recent aerial photography by an AVI certified photo interpreter. The photo interpreter further stratified each of the polygons into smaller fragments using canopy cover broken down into 10% canopy cover (CC) classes. A sample methodology was designed to sample each of the polygons to obtain information on stand characteristics such as species, basal area (BA), quadratic mean diameter (QMD), density, height, breast height age and site index. After all the sampling was done, the data were compiled and prepared for analysis.

3.2.1.1 Study Locations

Two areas, Lac La Biche and Grande Prairie, were selected for this study. These areas represented geographically different regions which permitted the testing of whether or not the potential relationships held on a larger geographical scale. Two companies, Weyerhaeuser Grande Prairie and Alberta Pacific Forest Industries Inc. (AL-PAC) offered support in form of local expertise, AVI maps, AVI coverage, and aerial photographs.

In Grande Prairie, the region used to identify aspen candidate polygons included townships 67 and 68, ranges 8 to 10, west of the 6^{th} meridian. The search area for spruce dominated polygons spanned townships 64 and 65, ranges 4 to 7, as well as townships 63 to 66 ranges 8 to 10, west of the 6^{th} meridian.

For Lac La Biche, the search area for both pure aspen and spruce dominated polygons was represented by townships 68 and 69, ranges 9 to 11, west of the 4^{th} meridian. The respective areas were selected because of easy access and the concentration of the polygons types of interest.

3.2.1.2 Polygon Selection Criteria

The focus of the study was to initially locate candidate polygons on inventory maps. The AVI map type call was used to characterize the polygon during the selection process.

Pure aspen (*Populus tremuloides* Michx.) (>80% aspen component by CC), C density polygons (51-70% canopy cover), larger than 10 hectares, with polygon heights between 19 and 23 m were selected (i.e. AVI map type call C20Aw8Pb2). The C density polygons with polygon heights between 19 and 23 meters represent the largest proportion of the inventory and are most variable (Lyseng, personal communication, 2006). This offered the greatest opportunity to find a range of polygons, homogeneous versus heterogeneous, and test volume variation across a range of differently stocked fragments as well as test whether mean polygon volume changed with degree of fragmentation.

For white spruce (*Picea glauca* (Moench) Voss), there were no pure spruce polygons (>80% spruce component by CC) available in the study areas, therefore the focus was on spruce dominated (>60% spruce component by CC), C density polygons (51-70% canopy cover), larger than 10 hectares, with polygon heights between 19 and 27 m.

3.2.1.3 Polygon Selection Process

Digital ArcGIS 9.1 (ESRI, Redlands, California) coverage was used to identify all polygons that met our selection criteria. From this selection, a sample of twenty two polygons was chosen favouring those that were easily accessible. A larger number of polygons were selected because of the likelihood that some would have been disturbed (logging or oil and gas) since the time of inventory. The polygons were then located on recent aerial photographs (2001–2004) and the AVI map type call was reconfirmed by a certified photo interpreter. The final step in the stands selection process involved a field visit.

In Grande Prairie the six selected pure aspen polygons had polygon heights between 19 and 22 meters and year of origin between 1910 and 1930, while the five spruce dominated polygons had polygon heights between 19 and 23 meters and years of origin between 1890 and 1920. In Lac La Biche the six selected pure aspen polygons had polygon heights between 19 and 22 meters and years of origin between 1910 and 1940, while the five spruce dominated polygons had polygon heights between 23 and 27 meters and years of origin between 1870 and 1900 (Table 3.1).

3.2.1.4 Assessing Fragmentation

Using recent aerial photographs of the selected polygons, ranging from 2001 to 2004, the smallest homogeneous areas, "fragments", were identified on the photos using 10% canopy cover classes. The interpretation was done directly on the photographs by a certified photo interpreter. The scale for all photos was 1:20,000, with one exception that was 1:15,000. There was no minimum fragment size and canopy cover was the only variable used in the fragment delineation process. The reinterpreted aerial photographs (including linework) were scanned at 1200 dots per inch resolution. ArcGIS 9.1 (ESRI, Redlands, California) was used to rectify the aerial photo scans to the Alberta Vegetation Inventory coverage permitting them to be overlaid.

The fragments with the same percent canopy cover (i.e. 80%) within a polygon were assumed to be similar in all other aspects (species composition, height, etc.) and viewed as a single "Stratum". The minimum, maximum and standard deviation of the fragments' area by polygon are presented in Table 3.2.

A "Population" is defined as the grouping of polygons with the same main species for one location (i.e. pure aspen polygons in Grande Prairie). In the present study four populations were delineated and the results presented individually.

3.2.2 Sampling Design

3.2.2.1 Plot Size

Circular (9.77 m radius) 300 m^2 plots were used to characterize each polygon. Larger plot sizes were preferred because they better capture stand variability and potentially decrease variability among plots. On the other hand the plot size had to be small enough to ensure relatively rapid data collection since the intensity of sampling was fairly high. Larger plots could also have conflicted with the small size of some of the delineated fragments.

3.2.2.2 Sampling Intensity

Given the plot size, sampling intensity by polygon and stratum needed to be determined based on a desired allowable error (AE) and precision. In order to determine the sampling intensity at the polygon level, some estimate of the volume coefficient of variation within our populations was required. These were calculated for the four populations using a sub-sample of local temporary sample plots (TSPs) provided by one of the supporting companies. The average coefficient of variation for both aspen and spruce dominated polygons was 55%. Using an allowable sampling error of 15% and t-statistic (α=0.2), the sample size was determined based on the simple random sampling formula for finite populations (Husch et al., 1972, Johnson, 2000).

The formula used was:

$$n_{stand} = \frac{N * t_{0.2}^2 * CV^2}{(AE\%)^2 * N + t_{0.2}^2 * (CV)^2} \qquad (3.1)$$

Where:

n_{stand} = the number of units needed to sample the stand at $\alpha = 0.2$ and sampling error AE% (15%).

N = the number of units in the polygon (300 m^2 plots; N = $Area_{polygon}/0.03$)

AE% = allowable sampling error in percent (15%)

$t_{0.2}$ = the t statistic at α=0.2 and n-1 degrees of freedom

CV = coefficient of variation for the TSP sub-sample

K = the number of plots in the TSP sub-sample

Results suggest that on average, twenty plots for each polygon, distributed over the different strata are required. The total number of plots varied slightly among polygons; the final number of plots located in each polygon is presented in Table 3.3.

3.2.2.3 Plot Allocation

The plots in each polygon were allocated to a stratum based on proportional allocation (Husch et al., 1972). Not all fragments received sample plots because the sampling process focused on characterizing stratum variation and not individual fragments. Using ArcView3.3 (ESRI, Redlands, California), the plots were randomly assigned using a random pixel selection routine to each stratum on the rectified photo scans. The polygons with the assigned plots were printed at scale 1:6,000 for use in the field. Photo scale was confirmed by measuring ground distances between recognizable photo points.

Plots with the center at less than 10 m from the fragment boundary, were moved 10 m into the fragment in a direction perpendicular to the fragment boundary.

3.2.3 Field data collection

The prints of the rectified polygon photographs were used to locate the plots and calculate bearings and distances from tie points identifiable on both the aerial photos and the ground. The plots were established in the field navigating from tie points using compass and 50 m chain. The location of each plot was recorded with a Global Positioning System (GPS) unit.

In each plot, all trees above 1.3 meters were measured and the species recorded. Diameter at breast height (DBH) was measured using a diameter tape and a caliper (trees smaller than 5 cm). Height was measured for all individuals using a Haglof vertex hypsometer. In two thirds of the plots, one or two dominant trees were cored at breast height using an increment borer.

To determine the breast height age of the individual trees, the cores were glued to wooden boards, sanded and the rings counted. The age and the height of the individual trees were then used to determine site index (height at reference breast height age 50) using regionally calibrated site index equations (Huang, 1997).

The total number of plots used to sample the four populations was 425 with 14,080 individual trees measured. The total number of tree cores taken was 420 in 268 plots.

3.2.4 Data compilation

In preparation for data analysis, individual tree, plot, stratum, polygon and population characteristics were calculated and summarized. All trees above 1.3 m were used in the calculations.

Individual tree volume was compiled using a regionally calibrated Kozak taper equation and an algorithm presented by Huang (1994). Total volume (m^3) (Tvol) was calculated for each stem and then summarized by plot.

Total plot basal area (m^2) (BA) was calculated for all species together by summing individual tree basal areas. Plot quadratic mean diameter (cm) (QMD) represents the diameter of the mean basal area stem. Plot QMD was calculated in three ways, including all trees above breast height, imposing a DBH tagging limit of 9 cm and a tagging limit of 15 cm at breast height, to test the effect of tagging limit. Top height, defined as the mean height of the largest 100 trees per hectare by diameter at breast height (Husch et al., 1972), was calculated in each plot using the three largest trees.

Total plot density was calculated by tallying all the individual trees. Density was also calculated using the tagging limits of 9 and 15 cm at breast height. Plot values for density, basal area, and volume were expanded to per hectare values by multiplying individual plot mean values with the tree expansion factor (tree factor = 10,000 m^2/plot size = 33.33).

Parameter means were also calculated by stratum, polygon, and population. The means were calculated by averaging the per hectare individual plot values within each stratum, polygon, and population, respectively.

3.2.5 Statistical analysis

The first step in data analysis was to summarize the stand characteristics and expand them to per hectare values by plot. Mean characteristics by stratum, polygon and population were calculated by grouping plot values. All statistical analyses were done using only individual plot values.

Statistical analyses were done to examine the relationship between plot total volume and canopy cover, our first objective, as well as the relationship between plot total volume and other stand characteristics or combinations of these explanatory variables, our second objective. Linear and multiple linear regression were used to investigate these two sets of relationships. As part of objective three, the relationship between calculated fragmentation indices and mean polygon volume was investigated at the population level using linear models.

To ensure that none of the assumptions of the linear regression were violated (normality and homogeneity of variances) data and models were graphically assessed using normal probability plots, box plots, and residual plots. Individual plots were considered to be independent although some degree of spatial autocorrelation may appear. No further testing of spatial autocorrelation was performed.

For the linear models, the regression procedure in SAS 8.3 was used to determine the model and the parameter's estimate significance. The multiple linear models were built starting from base linear models such as: basal area, quadratic mean diameter, top height, breast height age and site index. The multiple linear models built avoided the use of highly correlated variables within the same model. The same 15 multiple linear models were evaluated for all the populations using the stepwise procedure (Proc Stepwise) in SAS 8.3. The model's significance was evaluated based on p-value (α=0.05). For this procedure a variable entered the model at α=0.15. A variable was kept in the model at α = 0.05. The significance for all linear models was assessed based on the p-value (α=0.05), R^2, and mean square error (MSE). The Akaike information criterion (AIC) was also used to assess each model. The parameters estimates were considered significant for all models at α=0.05.

3.2.5.1 Plot, Stratum, and Polygon Summaries

Mean values, standard deviations, and coefficients of variation were calculated by plot, strata, and polygon for each of the polygon characteristics using per hectare values.

The compiled data by plot, stratum and polygon were graphed to look for trends. DBH histograms were built for each stratum and polygon. Scatter plots with volume, basal area, top height, quadratic mean diameter, density, breast height age, and site index by canopy cover were built by stratum and polygon.

These graphs showed trends in the data and were used to determine potential outliers. One spruce dominated polygon (polygon 406) was removed from the analysis because mean height and age were too far outside the population range.

3.2.5.2 Canopy Cover and Volume Relationship

The first objective of this study was to assess the strength of the relationship between canopy cover (10% units) and volume (m^3), and to determine if volume can be directly predicted from canopy cover. Individual plot values for volumes were used to fit the model.

The general linear model used was:

$$Y_i = b_0 + b_1X_i + \varepsilon_i \qquad (3.2)$$

Where Y_i represents the dependent variable, in this case total plot volume (m^3), X_i the explanatory variable, in this case stratum canopy cover (10% units), b_0 is the model's intercept, b_1 is the parameter estimate (slope), and ε_i is the error.

3.2.5.3 Canopy Cover and Other Variables

The explanatory power of canopy cover in relationship to other stand characteristics was also investigated. The purpose for the analysis was to determine whether canopy cover had the ability to explain variation of other stands characteristics.

In the linear regression model (3.2), the dependent variable Y_i became subsequently basal area (m^2), top height (m), density (n), quadratic mean diameter (cm), breast height age (years), and site index (m), while X_i, the explanatory variable, was canopy cover (10% units). Nine and 15 cm tagging limits were used in calculating density and QMD.

3.2.5.4 Relationship between Volume and Other Variables

The source of volume variation was under scrutiny for this particular study, as expressed in our second objective. The relationships between total plot volume and stand characteristics measured in the field were investigated. In the linear model (3.2), the dependent variable was total plot volume, while the explanatory variables were basal area, top height, density, quadratic mean diameter, breast height age, or site index.

Several other multiple linear models were developed around some of the previously mentioned base models (BA, top height, QMD, density). The general equation used to describe the multiple linear relationship was the following:

$$Y_i = b_0 + b_1X_1 + b_2X_2 + \ldots + b_kX_k + \varepsilon_i \qquad (3.3)$$

In the general, model (3.3) the dependent variable (Y_i) was total plot volume (m^3) while the explanatory variables (X_k) were represented by different stand characteristics (BA, top height, QMD, density, CC, SI, and breast height age). The same models (15) were tested for each population (i.e. Table 3.17), however not all variables included in the model were significant across all populations.

3.2.5.5 Regional Applicability of Relationships

Whether or not the models used for each population were similar and could have been replaced with a single relationship across all populations or group of populations was also of interest.

The general linear model used to test the difference between the two locations was:

$$Y = b_0 + b_1X + b_2Z + b_3XZ + \varepsilon_i \qquad (3.4)$$

In the general model (3.4) Y is the dependent variable, X is the explanatory variable, b_i are the model's parameters, Z is the dummy variable taking value 1 for Grande Prairie and 0 for Lac La Biche.

The dummy variable method was used to test the parallelism (H_0: $b_3 = 0$) or coincidence (H_0: $b_2 = b_3 = 0$) for some of the developed models across the two study areas (Kleinbaum and Kupper, 1978). The dummy-variable method was used only when the pooled variance estimates were found to be appropriate (the variances were homogeneous), based on an F test (H_0: $\sigma^2_A = \sigma^2_B$; H_A: $\sigma^2_A \neq \sigma^2_B$) (Kleinbaum and Kupper, 1978).

Our first two objectives for the study were to identify a relationship between volume and canopy cover or other stand characteristics, which would be useful in volume adjustments across the landscape. Model parallelism would imply that there was a different intercept between the regions, but since the slopes were the same, the rate of change is similar across the two areas of interest. Model coincidence would imply that a single relationship could be inferred and used across all data, therefore a more general relationship could be developed.

3.2.5.6 Fragmentation Indices

Our third objective was to test the potential use of fragmentation indices in characterizing polygon heterogeneity and in describing mean polygon volume variation. Three indices, dealing with fragmentation at the landscape level, were adapted from the literature to suit our study by incorporating canopy cover in the formulas. The indices were: number of patches (NP), largest patch index (LPI), and mean patch size (MPS) (Garcia-Giggoro and Saura, 2005). The indices were calculated for each individual polygon.

Fragmentation indices were calculated using both individual values for canopy cover as well as four classes of canopy cover. The four classes of canopy cover, going from one to four, grouped the individual values in four categories, 0-29%, 30-54%, 55-79%, and 80-100%. The formulae for the indices are the following:

1). Sum of canopy covers (SC):

$$NF_1 = \sum_i cc_i \qquad (3.5)$$

$$NF_2 = \sum_i w_i, \qquad (3.6)$$

NF_1 = index for the number of fragments modified with canopy cover

NF_2 = index for the number of fragments modified with a weighting factor

P_i = area in hectares of the individual fragment

CC_i = canopy cover associated with the individual fragment

W_j = weight class (1-4), calculated for each individual fragment. Weight values correspond to canopy cover class from Table 2.1

2). Mean fragment size (MFS):

$$MFS_1 = \frac{\sum_i p_i * cc_i}{n_i} \qquad (3.7)$$

$$MFS_2 = \frac{\sum_{ij} p_i * w_j}{n_i} \qquad (3.8)$$

MFS_1 = mean fragment size modified with canopy cover

MFS_2 = mean fragment size modified with a weighting factor

P_i = area of the individual fragment

CC_i = canopy cover associated with the individual fragment

W_j = weight class (1-4), calculated for each individual fragment

N_i = number of fragments in the polygon

3). Largest fragment index (LFI):

$$LFI_1 = Max\ (p_i) * cc_i \qquad (3.9)$$

$$LFI_2 = Max\ (p_i) * w_j \qquad (3.10)$$

LFI_1 = largest fragment index modified with canopy cover

LFI_2 = largest fragment index modified with a weighting factor

Max (P_i) = area of the largest individual fragment in the polygon

CC_i = canopy cover associated with the individual fragment

W_j = weight class (1-4), calculated for each individual fragment

Higher values for the indices were correlated with better stocked areas and higher canopy covers. A highly fragmented polygon, with low stocked fragments will have lower fragmentation indices than a homogeneous, highly stocked polygon.

3.2.5.7 Species Composition

We assessed the species composition correspondence between the AVI map type call and the data collected in the field at the polygon level. Species composition in AVI is determined based on the canopy cover proportion of each species at the polygon level. Species volume was used to determine species composition from the collected data. The basis for using volume to determine composition comes from its very strong correlation to basal area. There is also a high correlation between the individual tree DBH and crown size (Hall, 2001), therefore the species distribution based on canopy cover is similar to that described by basal area. The species distribution was graphically assessed by volume at the polygon level and compared with the canopy cover species distribution described in AVI.

3.3 Results

3.3.1 Summary Statistics

A summary of species composition, canopy cover class, polygon height and stand origin from the AVI map type calls for the 21 polygons used in the analysis is presented in Table 3.1. The comparison between the AVI density class type call and the range of canopy cover found from the photo interpretation showed that only one polygon has strata entirely within the C density canopy cover class limits (50-70%), while the other 20 polygons have at least one stratum of canopy cover outside the specified C class range (Table 3.2). The compiled data by plot were summarized by strata and polygon with the minimum, maximum, mean, range, standard deviation, and coefficient of variation calculated for each of the variables of interest (volume, basal area, top height, quadratic mean diameter, density, breast height age, and site index).

The data summaries by polygon (Table 3.3, 3.4 and 3.5) show the minimum, maximum, range, mean, standard deviation, and coefficient of variation for polygon characteristics, compiled with data collected in the field. The results show a wide variation around the mean for all stand characteristics. The volume range within pure aspen polygons varies between 199.7 m^3/ha (polygon 1610) and 785.6 m^3/ha (polygon 506), while for the spruce dominated polygons range values vary between 232.9 m^3/ha (polygon 532) and 720.2 m^3/ha (polygon 1676). Basal area range also varies within polygon between 21.2 m^2/ha (polygon 1610) and 77.8 m^2/ha (polygon 506) for pure aspen polygons while for the spruce dominated ones it varies between 24.3 m^2/ha (polygon 1454) and 57.6 m^2/ha (polygon 1676) (Table 3.3). Top height range within pure aspen polygons is above 8 m up to 21.3 m, while for the spruce dominated polygons the range varies between 4.5 m and 19.8 m. Quadratic mean diameter range varies between 6.1 cm and 29.2 cm across pure aspen polygons and between 10.9 cm and 29.1 cm for spruce dominated polygons (Table 3.4). Total density range varies between 667 and 2900 stems per hectare for the pure aspen polygons, and between 967 and 4000 stems per hectare for the spruce dominated polygons (Table 3.5). Site index range varies between and 4.3 m and 11.4 m for pure aspen polygons, while for the spruce dominated polygons the site index range varies between 3.1 and 13.1 m. Breast height age varies between 17 years and 75 years for the pure aspen polygons, while for the spruce dominated ones breast height age varies between 12 and 95 years (Table 3.5).

The compiled field data show substantial variation at the stratum level. Volume range within strata varies between 0 and 689.8 m^3/ha for pure aspen polygons, with more than half the strata having ranges above 100 m^3/ha, (Table 3.6). For the spruce dominated polygons the volume range within strata varies between 0 m^3/ha and 514 m^3/ha, with more than half the strata having range values above 100 m^3. The range of top height varies between 0.3 m and 15.4 m with half the strata above four meters for the pure aspen polygons, while for the spruce dominated polygons the range of top height varies between 0.1 m and 13 m (Table 3.7). Quadratic mean diameter range within strata varies from 1.3 to 21 cm, with, more than half the strata above 5 cm for the pure aspen polygons, and between 0.3 and 27.2 cm for the spruce dominant polygons (Table 3.7).

Density range varies at the strata level from 33 stems per hectare to 2300 stems per hectare, with more than half the strata having differences larger than 500 stems per hectare for the pure aspen polygons, while for the spruce dominated polygons density varies between 33 and 3467 stems per hectare (Table 3.8). The range of site index by strata for pure aspen polygons varies between 0.1 m and 8.2 m, while for the spruce dominated polygons the range varies between 0.1 m and 12.4 m (Table 3.8). For the pure aspen polygons the breast height age range varies by strata between 1 and 59 years, while for the spruce dominated polygons breast height age varies by strata between 1 and 95 years (Table 3.8).

The coefficients of variation for each polygon characteristic were regressed by population against canopy cover in an effort to understand whether variation decreased with increasing canopy cover. Results show that only eight out of the 28 linear models relating coefficients of variation for volume, basal area, density, top height, quadratic mean diameter, breast height age, and site index to canopy cover were significant ($\alpha=0.05$). From these eight models, two showed an increase in coefficients of variation in better stocked fragments. The graphs showing the scatter of coefficients of variation together with the significant models are presented in Appendix III.

3.3.2 Linear Relationships with Canopy Cover as Explanatory Variable

3.3.2.1 Aspen - Grande Prairie

Models linking volume, basal area, density, and top height to canopy cover were significant (α=0.05) for aspen dominated polygons in Grande Prairie (Table 3.9). Models relating quadratic mean diameter, site index and breast height age to canopy cover were not significant (α=0.05).

There was a weak but significant relationship between canopy cover and volume (R^2 = 0.16, p-value < 0.01, MSE = 19840, N = 111). This relationship suggests that for every 10% increase in canopy cover, volume increased by 31.61m^3. Both intercept and parameter estimates were significant (α=0.05). For basal area, density, and top height the variation explained was low (R^2 values were 0.19, 0.06, and 0.13 respectively).

3.3.2.2 Aspen - Lac La Biche

Models linking volume and basal area to canopy cover were significant (α=0.05) for aspen dominated polygons in Lac La Biche (Table 3.10). Models relating quadratic mean diameter, density, top height, site index, and breast height age to canopy cover were not significant (α=0.05).

There was a weak but significant relationship between volume and canopy cover (R^2 = 0.10, p-value < 0.01, MSE = 7084, N = 125). This relationship suggests that for every 10% increase in canopy cover volume increased by 18.5 m^3. Both intercept and parameter estimates were significant (α=0.05). For both volume and basal area the variation explained was low with an R^2 of 0.10.

3.3.2.3 Spruce - Grande Prairie

Models linking basal area, quadratic mean diameter, and density to canopy cover were significant (α=0.05) for spruce dominated polygons in Grande Prairie (Table 3.11). Models relating volume, top height, site index and breast height age to canopy cover were not significant (α=0.05) (Table 3.11).

There was a weak but significant relationship between basal area and canopy cover ($R^2 = 0.14$, p-value < 0.01, MSE = 75, N = 65). The relationship suggests that for a 10% increase in canopy cover basal area increased by 2.27 m^2. The significant models explained little variation, R^2 ranged between 0.10 for quadratic mean diameter and 0.21 for density.

3.3.2.4 Spruce - Lac La Biche

Models relating volume, basal area, and density to canopy cover were significant (α=0.05) for spruce dominated polygons in Lac La Biche (Table 3.12). The models linking quadratic mean diameter, top height, site index, and breast height age to canopy cover were not significant (α=0.05) (Table 3.12).

There was a weak but significant relationship between canopy cover and volume ($R^2 = 0.15$, p-value < 0.01, MSE = 14933, N = 100). The relationship suggests that for a 10% increase in canopy cover volume increased by 37.2 m^3. The significant models have low R^2, between 0.08 for density and 0.20 for basal area.

3.3.3 Linear Relationships with Volume as Dependent Variable

3.3.3.1 Aspen - Grande Prairie

Models relating all variables (QMD, BA, density, top height, breast height age, and site index) to plot volume were significant (α=0.05) for individual plots in pure aspen polygons in Grande Prairie (Table 3.13).

Notably the relationship between top height and volume was significant (α=0.05) ($R^2 = 0.53$, p-value < 0.01, MSE = 10969, N=111). The relationship suggests that for each meter increase in top height volume increased by 28.8 m^3. The R^2 varies greatly between significant models, from 0.04 for density to 0.90 for basal area.

3.3.3.2 Aspen - Lac La Biche

Models relating quadratic mean diameter, basal area, top height, site index, breast height age to volume were significant (α=0.05) for individual plots in pure aspen polygons in Lac La Biche. The model relating density to volume was not significant (α=0.05) (Table 3.14).

Most importantly, the model relating top height to volume was significant (α=0.05) (R^2 = 0.27, p-value < 0.01, MSE = 5782, N = 125). The relationship suggests that for each meter increase in top height, volume increased by 17.7 m^3. Variation explained by the significant models varies from an R^2 of 0.06 for site index to 0.84 for basal area (Table 3.14).

3.3.3.3 Spruce - Grande Prairie

Models relating quadratic mean diameter, basal area, top height, site index, and breast height age to volume were significant (α=0.05) for individual plots in spruce dominated polygons in Lac La Biche. The model relating density to volume was not significant (α=0.05) (Table 3.15).

Most importantly, the relationship between top height and volume was significant (R^2 = 0.53, p-value < 0.01, MSE = 3723, N = 65). The relationships strength varies from R^2 = 0.11 for site index to R^2 = 0.77 for basal area (Table 3.15).

3.3.3.4 Spruce - Lac La Biche

Models relating quadratic mean diameter, basal area, top height, and breast height age to volume were significant (α=0.05) for individual plots in spruce dominated polygons in Lac La Biche. The models relating density and site index to volume were not significant (α=0.05) (Table 3.16).

Notably, the relationship between top height and volume was significant (R^2 = 0.38, p-value < 0.01, MSE = 10056, N = 98). The relationships strength varies, R^2 increasing from 0.18 for breast height age to 0.91 for basal area (Table 3.16).

3.3.4 Multiple Linear Relationships between Volume and Other Variables

Starting from the base models explaining volume variation described in section 4.3, several multiple linear models were also developed by including other variables such as basal area, top height, quadratic mean diameter, and breast height age. The purpose for their development was to find stronger relationships.

3.3.4.1 Aspen - Grande Prairie

The results for pure aspen polygons in Grande Prairie show that some of the previously discussed linear models improved when several variables were used to explain volume variation in a multiple linear model.

The base model relating basal area to volume was significant (α=0.05) (R^2 = 0.90) (Table 3.13). When canopy cover was added to this base model volume predictions did not improve. When site index and breast height age were added to the base model, the model's prediction improved (R^2 = 0.93, p-value < 0.01, MSE = 1476, N = 86) (Table 3.17).

The model relating top height to volume was significant (α=0.05) (R^2 = 0.53) (Table 3.13). The model's predictions were not improved when breast height age was added to the base model. When canopy cover was added to the base model the variation explained increased (R^2 = 0.55, p-value < 0.01, MSE = 10612, N = 111) (Table 3.17).

Adding density and age to the base top height model increased the variation explained (R^2=0.60). When density was replaced in the previous model with density of trees above selected tagging limits (9 cm or 15 cm), the relationships were stronger with R^2 of 0.67 and 0.71 respectively (Table 3.17).

When canopy cover was added to the quadratic mean diameter base model the relationship was stronger, R^2 = 0.36 (Table 3.17). When breast height age and site index were added to the quadratic mean diameter base model, the R^2 increased to 0.46 (Table 3.15).

A model based on site index and breast height age had an R^2 of 0.33. When density is added to this model, the R^2 becomes 0.42. A model including only canopy cover, site index and breast height age had an R^2 of 0.39.

3.3.4.2 Aspen - Lac La Biche

The results for pure aspen in the Lac La Biche population show that the base models were improved when several other variables were added. Adding canopy cover to the base model relating basal area to total volume did not improve predictions, R^2 remained 0.84 (Table 3.14). Adding site index and breast height age to the basal area base model improved volume predictions (R^2 = 0.93, p-value < 0.01, MSE = 443, N = 85) (Table 3.18).

Adding canopy cover to the top height base model improved the R^2 to 0.32. Adding breast height age and density of trees above 9 cm to the top height base model further improved the relationship (R^2 = 0.37). Replacing density above 9 cm with density of trees above 15 cm further improved the previous model, the R^2 became 0.60 (Table 3.18).

When canopy cover was added to a base quadratic mean diameter model the relationship improved, R^2 = 0.40. Further adding site index and breast height age did not improve the model (Table 3.18).

A model relating site index and breast height age to volume had the R^2 0.21. Adding canopy cover to the previous model further improved the relationship, R^2 = 0.25 (Table 3.18).

3.3.4.3 Spruce - Grande Prairie

The results for spruce dominated polygons in Grande Prairie show that the explained volume variation increased when several variables were used in a multiple regression model. Adding canopy cover to the base basal area model did not improve predictions. Adding site index and breast height age to the base basal area model increased the explained variation (R^2 = 0.91, p-value < 0.01, MSE = 518, N = 38) (Table 3.19).

Adding canopy cover to the base top height model improved the relationship, R^2 = 0.57. When density of trees above 9 cm and breast height age were added to the top height base model the R^2 became 0.60. When density of trees above 15 cm replaced density above 9 cm in the previous model, the R^2 became 0.69 (Table 3.19).

Adding canopy cover to the base quadratic mean diameter model improved the relationship, R^2 =0.34 (Table 3.19). A model including breast height age and site index had an R^2 of 0.21 (Table 3.17).

3.3.4.4 Spruce - Lac La Biche

The results for spruce dominated polygons in Lac La Biche show that the explained volume variation increased when several variables were added to the previous base models. The base model relating basal area to total volume was not improved by adding canopy cover, R^2 = 0.91. When site index and breast height age were added to the base basal area model the predictions were marginally improved (R^2 = 0.92, p-value < 0.01, MSE = 621, N = 48) (Table 3.20).

Adding breast height age to a top height base model improved the R^2 from 0.38, the base model, to 0.41.When canopy cover was added to the top height base model the relationship improved, R^2=0.45 (Table 3.20).

When density of trees above 9 cm and breast height age were added to the top height base model the relationship improved, R^2 = 0.47. When density of only trees above 15 cm was used based on the previous model, the R^2 changed to 0.57 (Table 3.20).

When canopy cover was added to the base quadratic mean diameter model the relationship improved R^2 became 0.39 (Table 3.20). A model relating breast height age and site index to volume had the R^2 = 0.27 (Table 3.20).

3.3.5 Regional Applicability of Relationships

Variances for the two aspen populations were not homogeneous and these data could not be pooled. The variances for the two spruce populations were homogeneous and the data were pooled. Several models explaining volume were tested for the spruce populations to see whether they were parallel or coincident. The results for testing at the individual plot level are presented below.

The models relating top height to volume were parallel for the two spruce populations ($F = 0.053 < F_{.95,\ 1,\ 161} = 3.9$), however intercepts were significantly different, indicating that the models did not coincide ($F = 9.96 > F_{.95,2,161} = 3.06$).

The models relating top height and canopy cover to volume were parallel for the two spruce populations ($F = 1.79 < F_{.95,\ 2,\ 159} = 3.06$), however these models did not coincide ($F = 8.08 > F_{.95,3,159} = 2.66$).

The models relating basal area to volume were not parallel for the two spruce populations ($F = 13.6 > F_{.95,1,161} = 3.06$).

The models relating quadratic mean diameter to volume for the two spruce populations were coincident ($F = 0.06 < F_{.95,\ 2,\ 161} = 3.06$). The models relating volume to canopy cover and quadratic mean diameter were also coincident ($F = 1.85 < F_{.95,3,159} = 2.66$.

3.3.6 Fragmentation Indices

The relationship between polygon mean volume and the polygon fragmentation index were assessed using linear regression across all populations, for each population separately and by species groups (aspen and spruce). No model was significant (α=0.05). There was no correlation between volume and any of the calculated indices (Figure 3.1).

3.3.7 Species Composition

The species composition inferred as the mean volume, by species and by polygon, from field data was compared to species composition from AVI polygon type call. Species mean percent volume and species mean volume by polygon are presented both in tabular (Tables 3.21 and 3.22) and graphical form (Figure 3.2). The differences between the species composition determined with field data and the species composition from the AVI map type call are discussed below for each population separately.

3.3.7.1 Aspen Populations

Grande Prairie

In Grande Prairie, the AVI polygon type calls designated two polygons as being 80% aspen, three polygons as being 90% aspen, and one polygon as 100% pure aspen, with small percentages of the other species, primarily balsam poplar and in one case white spruce (Table 3.1). However, the actual percentage of balsam poplar in polygons was largely different from the AVI map type calls. In three polygons balsam poplar percentage was greater than 50% (polygon 506, 97, and 124). The other two polygons had volume percentages of balsam poplar above 27%. The mean total volume of balsam poplar per hectare ranged between 160 and 176 m^3 per hectare for three polygons, while for other two polygons the balsam poplar mean volume was above 80 m^3 per hectare (Table 3.21) (Figure 3.2).

Lac La Biche

In Lac La Biche, the AVI polygon type call characterized three polygons as being 100% pure aspen, while the other three polygons were described as having a 90% aspen component by canopy cover with small percentages of balsam poplar and white spruce (Table 3.1).

The species proportion compiled with field data was similar to the AVI map type calls. Only one aspen dominated polygon (1430) in Lac La Biche area had 40% of volume represented by a mixture of white spruce, balsam poplar, balsam fir (*Abies balsamea* (L.) P. Mill.), and birch (*Betula papyrifera* Marsch.). Four aspen dominated polygons had other species in the mixture in a proportion below 15%, mainly balsam poplar and spruce. Polygon 154 had 23% of its volume represented by spruce, balsam poplar and birch (Figure 3.2) (Table 3.21).

3.3.7.2 Spruce populations

Grande Prairie

In Grande Prairie, the AVI polygon type call characterized two polygons as having 70% white spruce in their composition and two polygons as having 80% white spruce in their composition, with added aspen, balsam poplar, fir or lodgepole pine (Table 3.1).

The species proportion compiled with the field data was similar to the species proportion in AVI map type calls. Three of the spruce dominated polygons from Grande Prairie had 30% down to 10% of their volume represented by other species than white spruce, mainly lodgepole pine (*Pinus cotorta* Dougl. e*x Loud var. latifolia* Engelm.), balsam fir, balsam poplar and aspen. One polygon (639) had 56% of the total volume represented by lodgepole pine and balsam fir (48% and 8%, respectively) (Figure 3.2) (Table 3.22).

Lac La Biche

In Lac La Biche, the AVI polygon type call characterized one polygon as having 60% spruce, one polygon as 70% spruce, two polygons as 80% spruce, and one polygon as 90% spruce, with small percentages of aspen, balsam poplar and fir (Table 3.1).

The species proportion compiled with the field data was similar to the species proportion in AVI map type calls. Four of the spruce dominated polygons in Lac La Biche had less than 37% down to 27% of their volume represented by other species than spruce, mainly aspen and balsam poplar. One spruce dominated polygon had 49% of its volume represented by balsam fir, balsam poplar, aspen and lodgepole pine, (Figure 3.2) (Table 3.22).

3.4 Discussion

3.4.1 Models with Canopy Cover as Explanatory Variable

The yield discrepancies between models built on temporary sample plots and models built on permanent sample plots became visible in Chapter 2 of this thesis. For a small number of similar polygons (similar AVI map type call), the yield differences between differently stocked fragments are quantifiable using canopy cover. Canopy cover was preferred for several reasons: it is readily available in AVI, it is correlated to stand volume per hectare (Avery, 1966) and it played a key role in stand volume tables that describe landscape volume (Gingrich and Meyer, 1955; Avery, 1958; Nyyssonen, 1957; Pope, 1962).

As previously presented, polygons are heterogeneous entities that can be seen as a grouping of "biological" stands. The scope of the study was to develop a polygon heterogeneity index based on the relationship between yield and canopy cover. This index would quantify polygon heterogeneity and link it to the mean polygon volume (yield). The first step in building an index was to assess and quantify the strength of the basic relationship between canopy cover and yield. The basic relationship was sought in four small populations of similar polygons for which two assumptions were considered true.

A first assumption of this study was that polygons delineated in the Alberta Vegetation Inventory were even-aged. AVI calculates the age of the polygon from decade of origin based on a disturbance (fire) map. The forest structure was considered even-aged for both species studied, although spruce polygons had mean ages between 90 and 140 years, while aspen polygons had mean ages above 70 years, based on AVI map call. The ontological stage for the two groups of species was different, since aspen above 70 years is in the break up stage showing ingress and regeneration (Peterson et al., 1996). For aspen, the even-age assumption is made because aspen is a shade intolerant species that regenerates abundantly from suckers after a disturbance, whether fire or harvest. Since the regeneration is massive and it happens immediately after disturbance, trembling aspen is generally believed to occur as even-aged, pyrogenic stands, which eventually develop into white spruce stands, are consumed by fire, or degenerate to brush land or meadows as the canopy of old stands collapses (Cumming et al., 2000).

A second assumption of the study was that the AVI polygon type call, based on aerial photographs, was highly correlated with the field data. As a corollary we assumed that a group of polygons with very similar map type calls would have similar stand characteristics.

The two assumptions, one related to forest structure, and the other one related to the accuracy of the AVI were considered to hold across both aspen and spruce polygons. Based on these assumptions a number of similar polygons were subdivided into smaller more homogeneous fragments based on 10% canopy cover classes. A strong relationship was expected between the canopy cover interpreted from aerial photos and actual volume measured in the plot across a small number of similar polygons (species composition, polygon height, and age). Once quantified, this relationship would have permitted us to further develop a canopy cover based index describing polygon heterogeneity and link it to mean polygon volume.

The results show that the relationship between canopy cover and volume is statistically significant but weak across three populations and not significant for the fourth. These results contradict our primary expectation of being able to relate volume and canopy cover. Furthermore, when canopy cover was used as the explanatory variable for any other stand characteristic (basal area, density, top height, site index, QMD, and breast height age), the relationships were weak or not significant. Even when the tagging limit was increased (9 cm and 15 cm) the density variation explained by canopy cover increased but remained below 30%. The reasons for such poor results can be found in the failure of our initial assumptions.

Although the results were similar across the two groups of species, they will be discussed separately for pure aspen and for the spruce dominated polygons.

There is a tendency to believe that aspen occurs predominantly in single-storied, even-aged stands, but there are a number of circumstances when a two-aged stand can develop (Peterson and Peterson, 1992). Kneeshaw and Bergeron (1998) state that aspen can regenerate in the understory before an aspen stand conversion to conifers. Cumming et al. (2000) showed that uneven-aged aspen stands are abundant and widespread in their study area, refuting the assumption that they were even-aged. These aspen stands begin gap formation at about 40 years after stand initiation and exhibit elevated recruitment, height growth, or survivorship of aspen saplings relative to areas beneath the closed canopies. As these stands age, a spatially heterogeneous age structure develops (Cumming et al., 2000). Larsen and Ripple (2003) show that aspen stands have successfully recruited new stems into their overstories in all habitat types from 1880 to 1989 in elk winter range on national forest areas surrounding the Yellowstone park. Betters and Woods (1981) show for some Rocky Mountain aspen stands that the break-up of the older canopy creates openings that stimulate sprouting and the development of younger aspen trees and that the stand structure in their study area seemed to be created by a gradual dying of the overstory. This was evidenced by the wide range in DBH and tree age in individual sample plots.

These studies show that the assumed simple structure of the aspen stands is more complex than previously acknowledged. Canopy cover may be appropriate in describing volume for an even-aged population of polygons with similar characteristics. However, canopy cover cannot describe volume variability in heterogeneous structures and uneven-aged polygons, since different volumes, generated by different DBH and age distributions, are described by the same percentage of canopy cover. Our results (see 3.3.1) also show a wide variability at the polygon and stratum level around all stand characteristics including breast height age.

Loewenstein et al. (2000) restates the Society of American Foresters definition of even-aged stands, from Helms (1998), as being a stand where the oldest and youngest tree differ by no more than 20% at rotation. According to this definition in an even-aged aspen stand with a 70 year rotation, the difference between the youngest and oldest aspen should not be larger than 14 years. Our results suggest that the polygon breast height age range is above 20 years for 17 out of the 21 polygons studied. Although the purpose of the study was not to investigate the age structure of polygons, which were assumed to be even-aged, our results together with several other studies on aspen stand structure suggest that the polygons are more variable than previously ackowledeged. The great variability in terms of breast height age is also supported by the DBH distribution at the polygon level presented in Figure 3.3.

The polygon DBH distributions display (Figure 3.3), in most cases, inverse J-shape curves characteristic of uneven-aged stands (Loewenstein et al., 2000). The large amount of regenerating trees, below 10 cm DBH, as well as the presence of individuals with large DBHs suggests that polygons in this study have a structure closer to an uneven-aged stand. The DBH distribution can be explained by the development of the aspen polygons through the gap formation process described by Cumming et al. (2000).

The spruce polygons were also considered even-aged and were subjected to the same hypothesis testing as the aspen dominated polygons. The results were similar to pure aspen polygons, suggesting the same issues, complex, uneven-aged structure (or at least uneven-sized), were present in the spruce dominated polygons.

Spruce, a shade tolerant species, can survive for decades under an aspen canopy and once the influence of the overstory aspen diminishes it is able to accelerate its growth and penetrate the overstory, becoming dominant and continuing its growth past the disappearance of aspen. It was expected for the spruce polygons to be more variable in structure since spruce regeneration is a slower process that can take place over considerably longer periods of time (Lieffers et al., 1996), often exceeding 50 years (Kabzems and Garcia, 2004). The slow rate of spruce recruitment in the understory of aspen is the process that leads to the variable age structure (Lieffers et al., 1996; Peters et al., 2006; Kabzems and Garcia, 2004).

As our results suggest, volume variation in spruce dominated polygons also had a different source represented by the other species found in the mixture, since pure spruce polygons were not readily available in our study area.

Although the reasons that lead to a complex stand structure (spruce continuously regenerates over a long time period and there are several species in the mixture) in the spruce dominated polygons are different than in the case of pure aspen polygons, the inverse J-shaped DBH distribution is present in most of the spruce dominated polygons marking the presence of more complex structures. The large range in breast height age for spruce is not necessarily indicative of uneven-aged structure for the spruce dominated polygons, since use of root collar rings combined with cross-dating is the proper method for aging spruce (Peters et al., 2002).

Another explanation for the intra-polygon variability resides in the criteria and the process of delineating polygons. Studies in the boreal forest refer to stands when in fact the borders of these "stands" were delineated on aerial photographs and represent polygons given criteria of the vegetation inventory (i.e. AVI) (Cumming et al., 2000). The definition of a stand is a contiguous group of trees sufficiently uniform in species composition, age-class composition, structure, and growing on a site of sufficiently uniform quality to be distinguished from surrounding stands and managed as a single unit (Helms, 1998; Robertson, 1971). This definition is more restrictive than the criteria used for delineating polygons such that the criteria for polygon delineation are not very rigorous. This is often due to minimum area restrictions, as in AVI where polygons cannot be less than 2 ha. The problem can be further compounded when larger variability in delineation criteria (mean height, canopy cover, etc.) is accepted for bigger polygons (10 ha or 20 ha). The delineation is a source of variability since the delineation process potentially mixes together areas with different history, structure and stage of development in the same polygon.

Age is another component of the AVI that is highly variable. The Alberta Vegetation Inventory records the age of a polygon from a landscape disturbance map, marking the last major fire in the area. However, the "stand-origin" estimates are best interpreted as modal age of the dominant canopy layer and cannot be assumed to equal stand age (Cumming et al., 2000). Huang and Heidt (1995) found that the correlation between field measured ages and interpreted origin ages was weak (R^2 = 0.3). Our results also showed a lot of variability when breast height age was determined in the field from dominant and co-dominant trees. This corroborates previous concerns about the inaccuracy of the "stand-origin" age concept.

One of the major assumptions in any inventory is that the species composition of the map call reflects the species composition of that polygon. Polygons were selected based on the proportion of the species of interest identified in the map type call. We expected that AVI species composition based on percent canopy cover would be similar to the field species composition based on percent volume since both variables are highly correlated to basal area (see 3.2.5.7). However, our results showed a discrepancy between the amount of aspen identified by the photo interpreter and the amount of aspen found in the field. This was especially true for the aspen dominated polygons in Grande Prairie.

It is difficult to differentiate between aspen and balsam poplar on a 1:20,000 aerial photograph. The photo interpreter needs multiple ground calls to be able to determine the proportion of balsam poplar in polygons (Lowell Lyseng, personal communication, 2006). Usually the proportion of poplar is determined based on a ground survey that indicates on average, for a larger area, the proportion of balsam poplar residing in polygons (Lowell Lyseng, personal communication, 2006).

Although the two species, aspen and balsam poplar, occupy the same area, there is some differentiation between the sites they appear on. Balsam poplar is frequently found on with wet depressions, as the species does not grow well on dry, exposed sites (Peterson and Peterson, 1992). Balsam poplar exhibits its best growth on moist, rich bottomlands with deep soil (Peterson and Peterson, 1992). Aspen and poplar often occur together on mesic sites, commonly with very few or no conifers. In some cases in Alberta as much as one-third of the basal area in polygons identified as aspen is actually balsam poplar (Peterson and Peterson, 1992). There is little information available on interspecific relations in sites where aspen and balsam poplar develop concurrently (Peterson and Peterson, 1992).

The species composition of aspen dominated polygons in Lac La Biche, determined from field data, was closer to the map type call. The aspen component was accompanied in a smaller proportion, under 20% from total volume, by balsam poplar, white spruce, white birch and balsam fir. Balsam poplar does not play a major role in the composition of aspen dominated polygons in Lac La Biche. The reasons may be related to the ecology of the species, polygons located in higher and dryer areas, and the spread of balsam poplar in the study area.

The differences in species composition should not be generalized to the entire area since the polygons selected were not representative for the townships the study was located in and the purpose of the study was not to assess the species distribution across the study area. However, the differences in species composition between the map type call and the field data were obvious for Grande Prairie aspen dominated polygons and were consistent with other observations (Peterson and Peterson, 1992).

The spruce dominated polygons in both locations had several species in their composition: lodgepole pine, balsam fir, aspen, and balsam poplar. The proportion of white spruce determined with the field data is similar to the map type call species distribution. The white spruce crowns are readily identifiable from an aerial photo, and are easier to separate from deciduous species. This would explain the higher accuracy of map type calls for the spruce dominated stands.

The large variability of stand characteristics both within and among polygons together with the complex structure of the forest within polygons, amplified by the delineating criteria, were responsible for the weak explanatory power of our base canopy cover models.

3.4.2 Linear Models Explaining Volume

The second objective was to analyze the relationship between different stand characteristics, measured in the field, and volume in an effort to test their ability to describe volume variation. The focus was on selecting variables that could be identified or measured from aerial photographs.

Field basal area predicts volume best for all populations, over 77% of the variation is explained. This is to be expected since volume and basal are known to be highly correlated. However, basal area is costly to measure in the field and difficult to assess from large scale photographs. Studies showed that it is possible to estimate diameter at breast height based on crown measures using large scale photographs (LSP) (1:2000) (Hall et al., 2001). However, this approach is laborious and requires significant effort since it is difficult to calibrate crown size DBH equations from large scale photographs.

Top height is generally preferred for explaining plot volume variation. Individual tree height can be estimated directly from large scale photographs (Hall et al., 2001), with better accuracy than other variables that are regression estimates, such as diameter at breast height. The same authors report an R^2 of 0.95 for white spruce and 0.79 for deciduous species in a regression between estimated large scale photos and field measured heights. Top height is a promising variable to be used in volume explanatory relationships mainly because it can be determined with better accuracy from large scale photographs. In this study top height explains between 27% and 53% of the variation in individual plot volumes.

Quadratic mean diameter explains between 20% and 33% of the variation in volume for all the individual plot models. Quadratic mean diameter is an indicator affected by density as it is inversely related to the square root of number of trees in the plot, for a certain basal area. In this study all trees above breast height were measured and used in density compilation. When regeneration and ingress are present, the density increases while the total basal area remains largely unchanged. This produces a decrease in quadratic mean diameter that is solely a density effect, which explains the reduced correlation between QMD and volume when tagging limits were not used. Quadratic mean diameter is also difficult to infer from an aerial photograph since it is calculated as the ratio of two difficult to assess variables: basal area and density.

Results show that breast height age was significant in explaining volume across all populations, but that relationships were weak. Since the relationship between the stand origin (the link to inventory) and the age determined in the stand is also weak (Huang and Heidt, 1995) and since the structure of the polygon is more complex than expected, breast height age would not be a preferred variable in explaining volume.

With one exception, site index explains some volume variation. Although the variability explained is below 11%, the models are significant, indicating a small site index effect across three out of four populations.

Huang and Titus (1993) suggest that in boreal forests with mixed-species composition the height-age relationship is very weak and that both site index and age are meaningless concepts in this situation. Avery and Burkhart (1994) suggest that site index is not an appropriate measure for productivity in uneven-aged stands and areas with mixed composition. The polygons in the study are naturally regenerated following fire and only a limited number of polygons (mostly in Lac La Biche area) have predominantly (>80%) aspen in their composition. In most of the cases the polygons represent a mix of several species, which explains the weak relationship between volume and site index.

AVI productivity values are based on a height-age relationship with age calculated from stand origin and polygon height. The results do not favor use of site index in explaining volume variation.

Density was not significant in three out of four cases in explaining volume variation. As shown by the coefficients of variation, density is quite variable between polygons as well as within the same stratum when it is calculated with all trees above breast height. Higher tagging limits shift DBH distribution towards larger trees, eliminating regeneration and ingress, and increasing the amount of volume variation explained by density. Due to difficulties in estimating the number of trees per hectare from aerial photographs and to the weak correlation to volume, density would not be a reliable variable for estimating volume for these complex structures.

The results show that top height is the preferred variable for explaining volume variation after basal area. As previously shown (Hall et al., 2001), there is a strong correlation between height estimates from large scale photographs and field measurements. Top height could be used to better differentiate fragments since top height's explanatory power is clearly higher than canopy cover's.

At the same time, the strong relationship between top height and yield contradict our initial assumptions about the study population stating that similar polygons (similar AVI) have no differences in stand characteristics, height in particular. Our results are similar to those of Gingrich and Meyer (1955), the only difference is that Gingrich and Meyer studied the entire landscape while the present study selected a number of similar polygons, based on very similar AVI type calls, specifically to minimize the variation in stand characteristics.

3.4.3 Multiple Models Explaining Volume

Following the second objective, additional variables were added to the linear base models in order to strengthen the relationship, increasing the explanatory power of the regressions. Models employing different combination of variables were used to determine which combination explains best volume variation. Particular attention was given to models using variables that could be determined from aerial photographs and could be easily added to or already existed in AVI.

The results showed that the best model for explaining volume variation across all populations was a model based on basal area, site index and breast height age. However, basal area is difficult to assess from aerial photographs, therefore the use of such a model to explain landscape volume distribution is limited. Other variables that are readily identifiable on the aerial photographs are more desirable to be used in explaining volume.

Models constructed using top height and canopy cover as independent variables explain from 32% to 57% of the volume variation. This model is preferred because it is based on one measure that is quantified from aerial photographs, canopy cover, and one independent variable estimated with field data, top height. Field measured top height could be substituted in the model with large scale photographs estimated top height.

The models based on top height, breast height age, and density calculated with different tagging limits explained 37-69% of the volume variation. Variation explained increased with the increase in the tagging limit used to calculate density. The variation explained by these models is larger than that explained by top height and canopy cover. Although models using density, especially when the 15 cm tagging limit is used, predict volume better than those using canopy cover, the number of trees above a certain tagging limit is difficult to assess from an aerial photo. These models are not practical since the variables they use are difficult to assess.

A model that uses canopy cover and quadratic mean diameter explained 34-40% of the plot volume variation across all populations. Quadratic mean diameter is a variable that is very difficult to assess on aerial photographs. It requires a large number of DBH estimates. The models based on quadratic mean diameter and canopy cover explain, with the exception of pure aspen Lac La Biche population, less of the volume variation compared with the previous sets of models discussed.

Models using site index, breast height age, and canopy cover as explanatory variables were significant only for the aspen populations, with lower R^2 than previously discussed models. These variables require field measurements (breast height age) or were based on equations calibrated for entire regions (site index). Due to uncertainty in variable estimation and poor R^2, these models were not preferred for future developments.

The preferred model for describing volume variation is a model based on top height and canopy cover. This model has two variables that can be easily determined from aerial photographs (top height and canopy cover) and explains in some cases up to 55% of yield variation. The results are consistent with the study by Gingrich and Meyer (1955) who based their aerial photo stand volume table on top height and canopy cover. However, the significant impact of top height on yield also shows the large variation that exists in our study populations and indicates problems with the stratification process based on AVI map type calls.

3.4.4 Comparing Models Across Locations

The comparison between locations was not possible for the two pure aspen populations because of heterogeneous variances between the two datasets.

For the spruce dominated polygons, the models relating top height to volume and the models relating top height plus canopy cover to volume were parallel. The models' slopes do not differ significantly between the two locations while the intercept is significantly different. The difference in intercept between the two populations represents a difference in productivity between the two locations. Non-linear models were not used to describe the data since the residuals for the linear models did not present any trend that would indicate non-linearity. The data was smoothed using Proc Loess in SAS 8.3 and the curve obtained overlaid the linear trend. Lack of data between 0 and 10% canopy cover may be the reason for an intercept significantly different from zero. The focus of the analysis was on estimating simple relationships that could be used in an index formulation.

The models relating quadratic mean diameter and quadratic mean diameter and canopy cover to volume were coincident, and a single model can be used to describe volume variation in the two locations.

3.4.5 The Use of Fragmentation Indices

Our third objective referred to assessing the ability of polygon fragmentation indices to describe mean polygon volume. The indices tested were based on range of canopy cover and the number and size of fragments. The fragmentation indices investigated did not explain the volume variation for the four populations, whether the testing was done by population or by species group. This was in part due to the lack of homogeneous polygons, and the low number of polygons in the study.

The value of any of the calculated indices was proportional to canopy cover and the area of the fragment. The maximum value for an index was attained when the entire polygon was fully stocked. The index decreased in different proportions by smaller fragments with lower stocking.

The sum of canopy covers was also tested as a fragmentation index. The lack of correlation between mean polygon volume and the formulated indices, combined with the weak explanatory power of canopy cover, indicate that a VLF based on canopy cover and fragmentation was not effective for these particular polygons. The proposed indices did not explain volume variation among polygons for our dataset. We had insufficient data and the selected polygons did not cover a sufficient range of fragmentation to permit the testing of a fragmentation index.

The polygon structural differences observed in the field and previously discussed point towards a complex polygon structure where the yield differences are better correlated with structural differences (mean size, top height) rather than stocking differences. The results suggest that top height and other variables that account for size (QMD) are the major drivers in yield variation, while variables related to stocking (canopy cover and density) are less important. This indicates that stratifying polygons based on AVI and further stratification based on canopy cover does not work for these study polygons. The yield variability within and among polygons with the same map type call is only marginally related to stocking.

From this perspective a fragmentation index based on canopy cover becomes less interesting since it has been shown that even for a small number of similar polygons the yield differences are better correlated with top height than canopy cover. The weak relationship between canopy cover and yield explains why indices based on canopy cover perform poorly in explaining mean polygon volume.

3.5 Conclusions

The first objective of the study was to assess the relationship between canopy cover and volume in four populations of polygons with similar AVI map type calls. Canopy cover was chosen as the principle variable to describe volume because it is indicative of stocking and it is easy to assess from aerial photographs. The larger objective was to calibrate a polygon level index based on stocking and fragmentation and to link it to mean polygon volumes, by integrating the base relationship between canopy cover and volume. Our results showed the base relationship was too weak to support further developments. The main reasons were linked to the variability found within our polygons. This variability had two sources, one referring to the structure of the natural boreal forest, which is more complicated than the assumed even-aged structure, and a second source referring to the variability introduced in the polygon (management unit) by the delineation process.

Several other models using variables measured in the stand better explain volume variation. The most interesting set of models is the one based on top height and canopy cover. The model has better predictive abilities and the two variables are easy to determine from aerial photographs. Stratifying the polygons based on these two variables might be more successful, since they account for both stocking and structure.

A study on younger post-harvest stands might also yield better results, since the regeneration on the harvested blocks took place in a shorter period of time, the structure is less complex and the delineated polygons are less variable since the harvested blocks are clearly defined. The variability associated with both structure and delineation criteria are presumably reduced in younger polygons.

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Table 3.1: AVI map type call based stand density class, polygon height (m), percent main species (10%), origin (yr), area (ha), and geographical coordinates for all study polygons

Population	Polygon	Density (class)	Height (m)	Main Sp.	Percent (%)	Origin	Area (ha)	Latitude	Longitude
	97	C	**19**	AW	90	1930	21.1	N54 46.648	W119 19.376
	103	C	**20**	AW	80	1920	65.5	N54 46.002	W119 18.859
AW_GP	124	C	**19**	AW	90	1930	54.6	N54 51.406	W119 21.723
	261	C	**20**	AW	80	1920	11.6	N54 53.508	W119 14.85
	289	C	**22**	AW	100	1910	27.6	N54 52.273	W119 08.967
	506	C	**20**	AW	90	1930	25.2	N54 48.51	W119 30.16
	411	C	**19**	SW	70	1910	12.9	N54 38.452	W118 53.04
SW_GP	639	C	**22**	SW	70	1900	51.5	N54 39.167	W118 45.451
	532	C	**19**	SW	80	1920	34.7	N54 39.139	W118 46.656
	511	C	**19**	SW	80	1920	11.9	N54 33.952	W119 27.296
	154	C	**20**	AW	100	1930	33.4	N54 55.088	W110 19.758
	1610	C	**21**	AW	100	1942	14.4	N54 52.152	W111 33.588
AW_LLB	1619	C	**20**	AW	90	1920	28.4	N54 52.004	W111 24.938
	1431	C	**22**	AW	100	1910	48.5	N54 51.787	W111 35.18
	1412	C	**19**	AW	90	1930	20.7	N54 51.598	W111 30.53
	1430	C	**21**	AW	90	1920	18.0	N54 51.392	W111 36.861
	1454	C	**24**	SW	90	1880	16.5	N54 51.864	W111 26.15
	1598	C	**25**	SW	70	1900	19.3	N54 51.533	W111 29.967
SW_LLB	1494	C	**28**	SW	80	1870	20.0	N54 51.753	W111 39.453
	1600	C	**26**	SW	60	1880	10.0	N54 51.477	W111 38.01
	1676	C	**28**	SW	80	1870	10.4	N54 51.465	W111 37.97

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.2: Number of fragments (N), minimum and maximum fragment canopy cover (10%), minimum, maximum, mean, and standard deviation of fragment area (ha) by polygon for all study polygons

Population	Polygon	N (fragments)	CC Min (%)	CC Max (%)	Min (ha)	Max(ha)	Mean(StdDev) (ha)
	97	8	60	90	0.76	6.0	2.6 (1.7)
	103	16	30	90	0.64	11.8	3.9 (3.5)
AW_GP	124	2	70	80	3.45	16.0	9.7 (8.9)
	261	8	10	70	0.38	6.1	1.6 (1.9)
	289	14	10	80	0.18	7.1	1.8 (1.9)
	506	16	10	90	0.24	3.7	1.4 (1.2)
	411	10	20	90	0.19	2.1	1.2 (0.7)
SW_GP	511	5	40	70	0.92	5.3	2.5 (1.7)
	532	13	20	80	0.71	7.6	2.8 (2.1)
	639	13	40	70	1.54	10.1	4.1 (2.4)
	154	17	10	90	0.52	4.9	2.0 (1.3)
	1412	11	30	80	0.38	11.6	1.9 (3.3)
AW_LLB	1430	12	40	70	0.76	3.0	1.5 (0.8)
	1431	14	10	90	0.46	12.0	3.3 (3.1)
	1610	4	60	70	1.92	8.5	3.7 (3.2)
	1619	12	40	80	0.33	10.8	2.5 (3.1)
	1454	11	50	80	0.39	4.3	1.6 (1.3)
	1494	7	40	70	1.04	6.1	2.9 (2.2)
SW_LLB	1598	14	30	90	0.30	3.2	1.4 (0.9)
	1600	4	40	70	0.80	4.9	2.7 (1.7)
	1676	6	10	70	0.26	4.2	1.6 (1.4)

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.3: Number of plots, minimum, maximum, range, mean, standard deviation, and coefficient of variation for basal area (m^2/ha) and volume (m^3/ha), by polygon for all study polygons

			BASAL AREA (m2/ha)					VOLUME (m3/ha)				
Population	Polygon	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
	97	20	15.0	49.5	34.5	35.1 (9.5)	27.1	122.1	465.6	343.5	291.8 (101.5)	34.8
	103	22	6.4	63.8	57.3	34.1 (14.0)	41.0	38.1	585.3	547.2	301.4 (149.6)	49.6
AW_GP	124	11	23.1	49.2	26.0	34.5 (9.3)	26.9	183.5	493.4	309.9	326.4 (111.1)	34.0
	261	16	21.1	70.5	49.4	36.7 (13.2)	36.0	191.8	621.6	429.8	333.8 (120.7)	36.1
	289	23	10.1	62.3	52.1	37.6 (13.1)	34.8	50.8	679.1	628.3	371.0 (165.8)	44.7
	506	19	5.1	82.8	**77.8**	35.7 (20.0)	56.2	21.9	807.4	**785.6**	294.6 (217.8)	74.0
	154	25	12.6	44.0	31.4	30.9 (8.0)	25.9	67.4	383.6	316.3	253.4 (83.8)	33.1
	1412	18	18.2	41.6	23.4	31.7 (4.9)	15.6	159.8	366.3	206.5	272.8 (49.2)	18.0
	1430	17	22.4	44.6	22.1	31.9 (6.0)	18.7	184.0	403.7	219.7	265.4 (60.9)	23.0
AW_LLB	1431	24	11.1	42.0	30.8	28.1 (8.8)	31.3	76.6	436.3	359.7	239.5 (85.6)	35.7
	1610	18	26.7	48.0	**21.2**	37.3 (6.9)	18.5	287.1	486.9	**199.7**	370.7(62.5)	16.9
	1619	23	16.3	58.5	42.3	32.4 (9.8)	30.4	118.5	539.8	421.3	297.6 (106.3)	35.7
	411	16	20.6	47.5	26.9	35.9 (6.8)	18.9	119.4	356.0	236.5	227.9 (54.1)	23.7
SW_GP	511	15	15.4	57.3	41.9	41.7 (12.0)	28.8	82.0	460.5	378.5	306.3 (101.5)	33.1
	532	18	20.1	50.5	30.4	37.2 (7.9)	21.3	138.0	370.9	**232.9**	255.1 (63.0)	24.7
	639	16	14.8	54.4	39.6	36.0 (9.4)	26.0	82.6	519.6	437.1	313.8 (104.9)	33.4
	1454	18	23.3	47.6	**24.3**	36.6 (6.7)	18.4	175.4	460.3	284.9	317.3 (82.2)	25.9
	1494	21	8.5	54.1	45.6	34.3 (11.7)	34.2	55.5	517.4	461.9	322.0 (132.5)	41.1
SW_LLB	1598	22	19.9	76.1	56.2	32.3 (12.7)	39.4	151.0	849.2	698.2	327.9 (148.8)	45.4
	1600	18	20.8	50.5	29.7	36.2 (7.8)	21.6	182.9	524.2	341.3	356.0 (91.1)	25.6
	1676	21	3.5	61.0	**57.6**	29.8 (15.1)	50.6	20.4	740.7	**720.2**	320.6 (177.8)	55.5

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.4: Number of plots, minimum, maximum, range, mean, standard deviation, and coefficient of variation for top height (m) and quadratic mean diameter (cm) by polygon for all study polygons

			TOPHT (m)					QMD (cm)				
Population	Polygon	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
AW_GP	97	20	20.0	28.7	8.7	24.9 (2.5)	10.0	16.7	31.0	14.3	22.0 (4.0)	17.9
	103	22	11.0	32.3	**21.3**	24.2 (4.6)	19.2	15.7	31.4	15.7	23.9 (4.0)	16.8
	124	11	22.5	30.5	**8.0**	27.0 (2.5)	9.3	23.0	36.3	13.4	28.4 (4.4)	15.4
	261	16	21.2	29.4	8.2	25.6 (2.4)	9.2	21.8	42.0	20.3	29.4 (6.4)	21.8
	289	23	14.4	30.4	15.9	25.7 (3.9)	15.1	7.4	34.8	27.4	25.0 (6.7)	26.9
	506	19	13.4	32.3	18.9	22.0 (4.5)	20.5	9.6	38.8	**29.2**	25.5 (7.4)	28.9
SW_GP	154	25	17.1	25.9	8.7	22.9 (2.4)	10.5	9.9	26.6	16.7	16.0 (3.5)	21.7
	1412	18	18.0	26.4	8.4	23.3 (2.5)	10.8	15.1	21.2	**6.1**	18.1 (1.7)	9.7
	1430	17	19.4	28.5	9.1	23.0 (2.3)	9.9	12.5	29.1	16.7	18.6 (4.1)	22.0
	1431	24	20.0	30.2	10.2	22.9 (2.5)	10.8	9.0	29.6	20.6	15.9 (4.6)	28.7
	1610	18	22.8	30.9	8.1	26.1 (1.9)	7.2	19.8	26.9	7.1	23.6 (2.0)	8.5
	1619	23	21.3	30.0	8.7	24.7 (2.4)	9.7	12.0	26.5	14.5	18.0 (4.6)	25.5
AW_LLB	411	16	16.2	20.7	**4.5**	18.1 (1.3)	7.4	9.6	20.8	11.2	13.8 (2.6)	18.5
	511	15	13.1	25.0	11.9	20.1 (3.0)	14.7	11.1	24.0	12.9	17.3(3.7)	21.5
	532	18	16.3	23.0	6.7	19.7 (7.1)	8.5	15.9	26.8	**10.9**	20.9 (3.5)	16.7
	639	16	14.7	27.7	13.0	22.7 (3.7)	16.4	12.7	35.0	22.3	21.1 (6.0)	28.6
SW_LLB	1454	18	20.0	30.4	10.3	24.6 (3.0)	12.1	11.9	33.9	21.9	18.5 (5.6)	30.1
	1494	21	17.9	31.7	13.8	26.2 (4.1)	15.7	10.9	39.4	28.5	26.5 (8.6)	32.6
	1598	22	21.1	32.3	11.2	28.0 (3.0)	10.6	11.6	40.7	**29.1**	27.7 (7.5)	27.2
	1600	18	22.3	31.5	9.2	27.8 (2.5)	9.1	16.0	43.3	27.2	27.8 (7.4)	26.6
	1676	21	15.2	35.0	**19.8**	28.8 (4.9)	17.2	18.2	44.0	25.8	30.7 (7.4)	24.2

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.5: Number of plots, minimum, maximum, range, mean, standard deviation, coefficient of variation, and number of plots for density (sph), site index (m), and breast height age (yr) by polygon for all study polygons

			DENSITY (sph)					SI (m)					BH_AGE (yrs)				
Population	Polygon	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
AW_GP	97	20	267	2067	1800	1022 (471)	46.1	17.3	27.7	10.3	21.9 (2.8)	12.9	56	82	26	66 (7.3)	11.1
	103	22	333	1767	1433	785 (381)	48.6	13.8	24.7	10.9	20.8 (3.2)	15.2	53	90	38	69 (8.8)	12.8
	124	11	233	900	**667**	570 (187)	32.7	21.1	25.4	**4.3**	23.0 (1.7)	7.2	69	86	**17**	77 (6.8)	8.9
	261	16	200	967	767	579 (231)	39.8	19.7	27.0	7.4	23.6 (2.6)	10.9	39	81	42	64 (10.9)	17.0
	289	23	200	2367	2167	888 (471)	53.0	13.3	24.0	10.7	21.1 (2.6)	12.4	56	131	**75**	83 (15.8)	19.0
	506	19	200	1500	1300	700 (307)	43.8	17.3	25.4	8.0	20.0 (2.4)	12.0	36	95	59	69 (15.6)	22.7
AW_LLB	154	25	233	3167	**2933**	1679 (610)	36.3	19.5	25.0	5.5	22.9 (1.5)	6.6	48	65	18	56 (5.4)	9.6
	1412	18	833	2167	1333	1276 (362)	28.4	17.6	26.8	9.2	22.9 (2.6)	11.3	49	62	13	56 (4.7)	8.5
	1430	17	367	2600	2233	1310 (541)	41.3	19.1	25.9	6.8	22.8 (2.0)	9.0	43	85	43	55 (9.9)	18.0
	1431	24	333	2933	2600	1567 (611)	39.0	16.3	24.8	8.4	21.2 (3.1)	14.6	49	85	36	70 (15.3)	22.0
	1610	18	567	1333	767	874 (236)	27.0	18.9	30.3	**11.4**	24.8 (2.9)	11.8	40	93	53	60 (11.8)	19.6
	1619	23	700	2400	1700	1410 (562)	39.9	15.6	25.6	10.0	21.7 (2.4)	10.9	57	85	29	72 (8.8)	12.2
SW_GP	411	16	1400	5400	**4000**	2560 (970)	37.9	17.1	23.8	6.7	20.3 (2.0)	9.7	44	55	**12**	47 (3.7)	7.8
	511	15	833	2733	1900	1873 (627)	33.5	16.2	27.3	11.1	22.1 (3.3)	15.0	37	96	59	47 (17.5)	37.1
	532	18	367	2133	1767	1209 (520)	43.0	19.3	27.4	8.1	24.0 (2.3)	9.8	25	46	21	38 (5.3)	14.0
	639	16	533	2133	1600	1192 (565)	47.4	13.8	16.9	**3.1**	14.8 (1.5)	9.8	92	129	37	111 (19.4)	17.6
SW_LLB	1454	18	433	2467	2033	1569 (592)	37.8	13.9	19.5	5.6	16.8 (2.0)	11.8	75	107	32	91 (11.2)	12.3
	1494	21	300	3533	3233	843 (782)	92.8	12.4	25.5	**13.1**	18.5 (3.6)	19.2	54	149	**95**	98 (23.2)	23.8
	1598	22	167	1933	1767	667 (450)	67.4	16.3	21.6	5.3	19.4 (2.1)	11.0	83	109	26	96 (9.3)	9.7
	1600	18	267	1333	1067	700 (335)	47.9	11.7	24.2	12.4	20.1 (3.6)	17.8	72	124	52	95 (17.0)	17.9
	1676	21	67	1033	**967**	444 (263)	59.1	-	-	-	-	-	-	-	-	-	-

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.6: Stratum canopy cover, minimum, maximum, range, mean, standard deviation, coefficient of variation for basal area (m^2/ha) and volume (m^3/ha) by polygon stratum for all study polygons

				BASAL AREA (m2)					VOLUME (m3)				
Population	Polygon	CC	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
	97	6	7	15.0	49.5	34.5	32.2 (12.0)	37.4	122.1	416.6	294.5	259.8 (92.1)	35.5
	97	7	6	26.3	47.2	20.9	35.8 (7.4)	20.7	154.5	465.6	311.1	288.9 (11.5)	38.6
	97	8	2	34.2	38.5	4.4	36.3 (3.1)	8.5	257.7	303.5	45.8	280.6 (32.4)	11.6
	97	9	5	18.7	45.1	26.3	37.7 (10.8)	28.7	128.9	423.8	294.9	344.9 (122.7)	35.6
	103	3	2	6.4	27.3	20.8	16.9 (14.7)	87.4	38.1	257.8	219.7	147.9 (155.3)	105.0
	103	4	2	11.6	24.2	12.6	17.9 (8.9)	49.8	70.8	185.8	115.1	128.3 (81.4)	63.4
	103	5	2	25.7	42.9	17.2	34.3 (12.2)	35.5	183.3	367.0	183.8	275.2 (129.9)	47.2
	103	6	2	39.5	63.8	24.3	51.6 (17.2)	33.2	296.3	585.3	289.0	440.8 (204.4)	46.4
	103	7	4	22.1	39.6	17.5	31.5 (8.9)	28.1	175.6	404.8	229.2	265.4 (98.3)	37.0
	103	8	8	22.7	58.0	35.3	36.9 (12.5)	34.0	189.0	584.1	395.1	349.0 (152.6)	43.7
	103	9	2	39.2	47.0	7.8	43.1 (5.5)	12.9	390.4	403.3	12.9	396.8 (9.1)	2.3
	124	7	3	23.1	32.9	9.8	27.9 (4.9)	17.6	183.5	285.2	101.7	224.0 (53.9)	24.1
AW_GP	124	8	8	24.2	49.2	25.0	37.0 (9.5)	25.8	229.5	493.4	264.0	364.8 (103.0)	28.2
	261	1	1	27.8	27.8	0.0	27.8	-	250.7	250.7	**0.0**	-	-
	261	2	1	23.0	23.0	0.0	23.0	-	214.6	214.6	0.0	-	-
	261	3	2	22.5	28.1	5.5	25.3 (3.9)	15.5	205.8	295.5	89.8	250.7 (63.5)	25.3
	261	6	5	34.5	70.5	36.0	48.5 (14.4)	29.6	296.5	621.6	325.1	415.0 (131.5)	31.7
	261	7	7	21.1	50.4	29.3	34.7 (9.4)	27.0	191.8	530.8	339.0	328.4 (113.3)	34.5
	289	1	1	10.1	10.1	0.0	10.1	-	50.8	50.8	0.0	-	-
	289	3	2	33.6	39.1	5.5	36.4 (3.9)	10.7	313.3	429.8	116.5	371.6 (82.4)	22.2
	289	4	2	13.6	28.3	14.7	20.9 (10.4)	49.8	110.8	279.3	168.5	195.0 (119.1)	61.1
	289	5	2	27.5	40.1	12.6	33.8 (8.9)	26.5	172.9	356.3	183.3	264.6 (129.6)	49.0
	289	6	7	21.1	62.3	41.2	39.6 (14.0)	35.3	162.2	679.1	516.9	381.3 (177.6)	46.6
	289	7	4	39.8	58.2	18.4	48.3 (8.6)	17.8	433.5	655.1	221.6	527.0 (109.5)	20.8
	289	8	5	32.2	54.8	22.5	40.5 (8.8)	21.8	315.4	591.2	275.9	408.6 (111.0)	27.2
	506	1	1	14.7	14.7	0.0	14.7	-	95.1	95.1	0.0	-	-
	506	2	2	5.1	12.1	7.0	8.6 (5.0)	58.0	21.9	87.2	65.4	54.4 (46.2)	84.7
	506	6	4	9.2	42.3	33.1	29.4 (14.9)	50.6	51.5	322.5	271.0	217.7 (125.5)	57.7
	506	7	3	27.4	37.7	10.3	33.7 (5.6)	16.5	185.8	259.7	73.9	234.3 (42.0)	17.9
	506	8	5	34.6	82.8	48.3	52.8 (19.7)	37.2	246.3	758.5	512.2	459.8 (211.8)	46.1
	506	9	4	15.6	65.7	50.1	40.7 (20.7)	50.8	117.6	807.4	**689.8**	380.0 (298.0)	78.4
	154	1	2	12.6	12.9	0.3	12.8 (2.1)	1.8	67.4	89.3	21.9	78.3 (15.5)	19.8
	154	3	2	17.9	24.3	6.4	21.1 (4.5)	21.4	93.0	168.9	75.9	131.0 (53.6)	41.0
	154	5	4	30.2	40.4	10.2	34.0 (4.4)	13.1	257.0	316.9	59.9	276.5 (27.6)	10.0
	154	6	6	26.2	36.6	10.3	32.4 (4.2)	12.9	215.0	341.3	126.2	266.0 (58.4)	22.0
	154	7	2	26.6	33.9	7.4	30.3 (5.2)	17.2	190.9	273.2	82.3	232.1 (58.2)	25.1
	154	8	4	28.9	42.8	14.0	35.1 (6.1)	17.3	231.4	341.0	109.6	294.3 (47.2)	16.0
	154	9	5	25.4	44.0	18.6	34.9 (6.8)	19.5	220.3	383.6	163.3	314.8 (61.8)	19.6
	1412	4	1	32.0	32.0	0.0	32.0	-	236.8	236.8	0.0	-	-
	1412	6	3	26.8	33.2	6.4	30.2 (3.2)	10.7	202.6	265.4	62.9	235.0 (31.5)	13.4
	1412	7	4	18.2	33.9	15.7	29.0 (7.3)	25.1	159.8	282.9	123.1	248.3 (59.4)	23.9
	1412	8	10	26.6	41.6	15.0	33.1 (4.5)	13.5	254.0	366.3	112.3	297.5 (40.2)	13.5
	1430	4	2	22.4	31.7	9.3	27.1 (6.6)	24.2	189.0	245.2	56.2	217.1 (39.7)	18.3
	1430	5	5	28.1	44.6	16.4	35.8 (6.3)	17.7	207.7	403.7	196.1	298.9 (39.7)	24.1
AW_LLB	1430	6	7	24.4	36.7	12.3	29.4 (5.2)	17.6	184.0	332.1	148.1	244.7 (53.9)	22.0
	1430	7	3	31.0	37.7	6.8	34.3 (3.4)	9.9	238.5	332.5	94.0	290.4 (47.8)	16.4
	1431	3	3	11.1	41.6	30.4	25.2 (15.4)	60.8	76.6	352.1	275.5	233.9 (141.8)	60.6
	1431	5	5	16.9	42.0	25.1	25.1 (10.0)	39.8	118.7	436.3	317.6	218.2 (127.1)	58.3
	1431	6	8	16.7	40.1	23.3	28.3 (8.8)	31.1	125.9	329.1	203.2	230.4 (73.7)	32.0
	1431	7	4	25.4	37.6	12.2	31.5 (6.1)	19.4	218.6	322.0	103.3	276.6 (43.5)	15.7
	1431	8	2	25.3	30.6	5.2	28.0 (3.7)	13.2	224.9	232.6	7.7	228.7 (5.4)	2.4
	1431	9	2	26.4	39.0	12.6	32.7 (8.9)	27.1	207.9	339.6	131.6	273.8 (93.1)	34.0
	1610	6	9	29.3	48.0	18.7	35.0 (6.9)	19.7	287.1	426.4	139.3	344.4 (56.9)	16.5
	1610	7	9	26.7	46.4	19.7	39.6 (6.4)	16.3	306.4	486.9	180.5	397.1 (59.2)	14.9
	1619	4	1	37.4	37.4	0.0	37.4	-	410.4	410.4	0.0	-	-
	1619	6	13	19.9	58.5	38.6	32.3 (9.6)	29.7	158.5	539.8	381.3	294.7 (95.1)	32.3
	1619	7	6	16.3	48.2	31.9	32.5 (11.9)	36.7	118.5	506.2	387.8	284.8 (133.4)	46.9
	1619	8	3	18.6	42.4	23.8	30.9 (11.9)	38.7	167.0	440.3	273.2	298.1 (137.0)	45.9
	411	2	1	20.6	20.6	0.0	20.6	-	119.4	119.4	0.0	-	-
	411	5	3	31.4	47.5	16.1	38.3 (8.3)	21.7	194.0	356.0	162.0	257.8 (86.3)	33.5
	411	6	3	30.1	45.1	15.0	35.2 (8.6)	24.3	191.8	302.5	110.7	233.0 (60.5)	26.0
	411	7	4	28.8	40.1	11.3	36.0 (5.0)	14.0	172.6	274.8	102.2	225.2 (41.7)	18.5
	411	8	5	32.6	41.9	9.3	37.8 (3.8)	10.0	197.2	251.4	54.2	230.8 (21.4)	9.3
	511	4	1	37.6	37.6	0.0	37.6	-	320.4	320.4	**0.0**	-	-
	511	5	4	15.4	55.6	40.1	33.9 (18.1)	53.3	82.0	377.3	295.3	242.3 (151.6)	62.6
	511	6	5	29.2	49.1	19.9	40.4 (7.7)	19.1	207.4	357.1	149.7	287.3 (54.2)	18.9
SW_GP	511	7	5	42.6	57.3	14.7	50.0 (6.9)	13.7	296.0	460.5	164.6	373.7 (74.9)	20.0
	532	2	2	29.5	37.0	7.5	33.3 (5.3)	16.0	209.9	231.1	21.2	220.5 (15.0)	6.8
	532	4	2	20.1	26.4	6.2	23.3 (4.4)	18.9	138.0	185.2	47.2	161.6 (33.3)	20.6
	532	5	3	34.1	42.9	8.9	39.1 (4.5)	11.6	216.7	294.2	77.5	260.0 (39.5)	15.2
	532	6	3	34.3	43.8	9.5	40.4 (5.3)	13.1	230.2	351.9	121.7	287.2 (61.2)	21.3
	532	7	4	33.7	50.1	16.3	40.5 (6.9)	17.1	203.3	370.9	167.6	283.6 (68.8)	24.3
	532	8	4	27.9	50.5	22.6	39.1 (9.4)	24.0	176.7	348.1	171.5	263.1 (70.1)	26.6
	639	4	4	14.8	54.4	39.6	30.4 (16.9)	55.7	82.6	519.6	437.1	244.7 (190.6)	77.9
	639	5	5	25.3	42.0	16.7	36.9 (7.0)	18.9	197.8	406.0	208.2	315.1 (75.9)	24.1
	639	6	4	35.1	36.7	1.6	35.8 (0.7)	2.0	319.9	354.7	34.8	335.7 (14.9)	4.4
	639	7	3	39.6	45.6	6.0	42.1 (3.1)	7.4	359.7	382.0	22.3	374.4 (12.7)	3.4
	1454	5	3	39.0	46.2	7.2	41.4 (4.2)	10.0	341.7	433.6	91.9	381.3 (47.3)	12.4
	1454	6	7	23.3	47.6	24.3	34.1 (8.6)	25.2	175.4	460.3	284.9	297.1 (94.7)	31.9
	1454	7	6	29.9	45.9	15.9	36.5 (5.9)	16.1	213.4	460.0	246.6	314.5 (89.6)	28.5
	1454	8	2	36.8	39.6	2.8	38.2 (2.0)	5.1	283.6	317.7	34.1	300.7 (24.1)	8.0
	1494	4	2	8.5	9.8	1.3	9.2 (0.9)	10.1	55.5	66.1	10.7	60.8 (7.5)	12.4
	1494	5	7	26.0	52.9	26.9	36.2 (9.0)	24.9	194.7	503.8	309.1	349.2 (102.8)	29.4
	1494	6	10	22.3	54.1	31.7	37.0 (9.6)	25.8	172.1	517.4	345.3	348.9 (120.5)	34.5
	1494	7	2	35.1	43.6	8.5	39.4 (6.0)	15.3	298.4	408.5	110.1	353.4 (77.8)	22.0
	1598	3	2	27.7	38.4	10.7	33.1 (7.6)	22.9	311.3	390.5	79.2	350.9 (56.0)	16.0
	1598	4	2	21.2	21.6	0.4	21.4 (0.3)	1.5	151.0	199.4	48.4	175.2 (34.2)	19.5
	1598	5	4	19.9	41.2	21.3	29.9 (10.6)	35.5	204.9	387.3	182.4	292.2 (93.9)	32.1
SW_LLB	1598	6	6	20.3	44.8	24.5	33.8 (8.2)	24.1	207.5	494.7	287.2	352.9 (97.2)	27.5
	1598	7	6	20.2	39.9	19.7	30.5 (7.9)	25.8	224.3	425.0	200.6	310.5 (77.2)	24.9
	1598	8	1	20.4	20.4	0.0	20.4	-	163.7	163.7	0.0	-	-
	1598	9	1	76.1	76.1	0.0	76.1	-	849.2	849.2	0.0	-	-
	1600	4	2	36.1	38.0	1.9	37.1 (1.3)	3.6	353.2	398.7	45.5	376.0 (32.2)	8.6
	1600	5	7	20.8	39.2	18.4	32.3 (6.3)	19.4	182.9	398.4	215.5	328.1 (74.1)	22.6
	1600	6	4	26.6	47.5	20.9	35.7 (9.5)	26.7	200.9	495.5	294.6	331.7 (129.2)	39.0
	1600	7	5	31.4	50.5	19.2	41.7 (8.3)	19.8	297.6	524.2	226.6	406.6 (94.3)	23.2
	1676	1	2	3.5	7.4	3.9	5.4 (2.8)	51.1	20.4	66.4	45.9	43.4 (32.5)	74.9
	1676	3	2	9.4	20.3	10.9	14.8 (7.7)	52.1	91.1	224.2	133.2	157.6 (94.2)	59.7
	1676	6	10	20.2	61.0	40.8	32.7 (13.4)	40.8	241.8	654.1	412.3	365.6 (144.5)	39.5
	1676	7	7	26.8	60.9	34.1	37.0 (11.6)	31.4	226.9	740.7	**513.7**	382.1 (173.8)	45.5

Table 3.7: Stratum canopy cover, minimum, maximum, range, mean, standard deviation, coefficient of variation for top height (m) and quadratic mean diameter (cm) by polygon stratum for all study polygons

				TOP HEIGHT (m)					QMD (cm)				
Population	Polygon	CC	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
	97	6	7	23.4	28.6	5.2	25.8 (1.9)	7.5	18.0	31.0	12.9	24.2 (4.3)	17.9
	97	7	6	20.0	27.1	7.1	23.1 (2.6)	11.4	17.7	25.5	7.8	21.9 (3.1)	14.0
	97	8	2	22.0	24.7	2.8	23.4 (2.0)	8.4	17.8	27.1	9.3	22.5 (6.6)	29.2
	97	9	5	22.9	28.7	5.8	26.3 (2.1)	8.1	16.7	21.2	4.6	19.0 (1.9)	10.0
	103	3	2	11.0	26.4	**15.4**	18.7 (10.9)	58.3	15.7	25.5	9.8	20.6 (6.9)	33.7
	103	4	2	18.9	21.0	2.1	19.9 (1.5)	7.3	19.2	29.0	9.8	24.1 (6.9)	28.7
	103	5	2	19.5	25.5	6.0	22.5 (4.2)	18.9	21.1	27.3	6.2	24.2 (4.4)	18.0
	103	6	2	19.9	26.9	7.0	23.4 (4.9)	21.1	19.0	25.7	6.7	22.3 (4.7)	21.2
	103	7	4	20.5	32.3	11.8	25.4 (5.0)	19.8	20.2	31.4	11.1	24.3 (4.8)	19.9
	103	8	8	21.3	29.7	8.4	26.4 (2.8)	10.6	21.6	28.7	7.1	25.6 (2.7)	10.4
	103	9	2	23.6	27.2	3.6	25.4 (2.5)	10.0	18.4	22.7	4.3	20.6 (3.0)	14.8
	124	7	3	22.5	28.2	5.7	24.4 (3.3)	13.4	23.0	31.1	8.1	25.9 (4.5)	17.6
AW_GP	124	8	8	26.2	30.5	4.3	28.0 (1.4)	5.0	23.6	36.3	12.7	29.4 (4.2)	14.4
	261	1	1	25.7	25.7	0.0	25.7	-	42.0	42.0	0.0	-	-
	261	2	1	21.2	21.2	0.0	21.2	-	33.1	33.1	0.0	-	-
	261	3	2	24.7	26.1	1.5	25.4 (1.0)	4.1	24.8	31.2	6.4	28.0 (4.5)	16.2
	261	6	5	23.9	28.8	4.9	25.9 (2.0)	7.6	23.9	38.7	14.7	32.9 (6.1)	18.6
	261	7	7	22.1	29.4	7.3	26.0 (2.8)	10.6	21.8	31.0	9.3	25.1 (3.6)	14.2
	289	1	1	14.4	14.4	0.0	14.4	-	7.4	7.4	0.0	-	-
	289	3	2	28.9	29.3	**0.3**	29.1 (0.2)	0.8	30.6	32.7	2.1	31.6 (1.5)	4.8
	289	4	2	24.7	25.8	1.2	25.3 (0.8)	3.3	23.3	29.4	6.1	26.3 (4.3)	16.5
	289	5	2	21.1	23.6	2.5	22.4 (1.7)	7.8	14.8	18.3	3.5	16.5 (14.8)	14.8
	289	6	7	20.7	30.4	9.7	25.2 (3.6)	14.2	18.3	34.8	16.5	26.9 (7.6)	28.0
	289	7	4	26.4	30.2	3.8	28.8 (1.7)	5.8	20.8	28.4	7.5	26.0 (3.5)	13.4
	289	8	5	23.3	29.5	6.2	26.3 (2.6)	9.9	22.4	27.3	4.9	25.1 (1.9)	7.5
	506	1	1	16.6	16.6	0.0	16.6	-	30.6	30.6	0.0	-	-
	506	2	2	13.4	22.1	8.7	17.7 (6.2)	34.8	9.6	16.5	6.9	13.0 (4.9)	37.4
	506	6	4	15.1	25.1	10.0	21.3 (4.3)	20.3	21.0	27.8	6.9	24.2 (3.5)	14.6
	506	7	3	19.9	22.7	2.8	21.0 (1.5)	7.2	25.7	27.5	1.8	26.8 (1.0)	3.8
	506	8	5	21.6	29.8	8.2	24.8 (3.4)	13.9	26.3	38.8	12.5	30.7 (4.8)	15.6
	506	9	4	20.4	32.3	11.9	23.6 (5.8)	24.5	12.7	33.7	**21.0**	24.1 (10.5)	43.5
	154	1	2	17.3	20.4	3.1	18.9 (2.2)	11.6	11.7	26.6	14.8	19.1 (10.5)	54.8
	154	3	2	17.1	21.8	4.6	19.5 (3.3)	16.8	9.9	13.4	3.5	11.6 (2.5)	21.4
	154	5	4	22.0	24.9	2.9	23.9 (1.3)	5.4	13.4	19.4	6.0	15.4 (2.7)	17.7
	154	6	6	19.5	25.9	6.4	23.8 (2.5)	10.4	13.9	18.6	4.7	16.0 (1.6)	10.2
	154	7	2	22.8	23.8	1.0	23.3 (0.7)	3.1	13.1	17.0	3.9	15.0 (2.7)	18.1
	154	8	4	20.7	24.8	4.1	22.6 (1.8)	8.2	12.4	18.9	6.4	15.6 (2.6)	17.0
	154	9	5	23.6	25.4	1.8	24.2 (0.7)	2.9	15.2	22.7	7.5	17.7 (2.9)	16.3
	1412	4	1	19.9	19.9	0.0	19.9	-	15.1	15.1	0.0	-	-
	1412	6	3	18.6	25.4	6.8	22.6 (3.6)	15.8	17.4	21.2	3.8	19.2 (1.9)	9.9
	1412	7	4	22.1	24.7	2.6	23.6 (1.1)	4.5	16.7	18.8	2.2	17.6 (1.0)	5.6
	1412	8	10	18.0	26.4	8.4	23.8 (2.7)	11.1	15.1	20.4	5.2	18.2 (1.7)	9.6
	1430	4	2	21.7	24.9	3.2	23.3 (2.3)	9.7	12.5	16.1	3.7	14.3 (2.6)	18.1
	1430	5	5	21.9	25.1	3.2	23.6 (1.5)	6.4	13.5	22.7	9.2	17.5 (3.9)	22.3
AW_LLB	1430	6	7	19.4	28.5	9.1	23.0 (3.2)	13.8	15.7	29.1	13.5	20.0 (4.6)	22.8
	1430	7	3	20.5	22.9	2.4	22.0 (1.3)	6.1	17.4	21.6	4.1	20.1 (2.3)	11.5
	1431	3	3	20.3	30.2	9.9	23.9 (5.5)	22.8	9.0	29.6	20.6	17.6 (10.7)	61.0
	1431	5	5	20.0	25.3	5.3	22.6 (2.0)	8.6	11.4	25.3	13.9	15.4 (5.8)	37.4
	1431	6	8	21.0	25.4	4.4	22.8 (1.5)	6.5	10.9	20.5	9.6	14.8 (3.0)	20.0
	1431	7	4	20.8	28.7	7.8	23.3 (3.7)	15.8	14.1	19.0	4.9	16.8 (2.0)	12.2
	1431	8	2	20.3	23.1	2.7	21.7 (1.9)	8.9	16.4	20.1	3.7	18.2 (2.6)	14.2
	1431	9	2	22.7	23.7	1.0	23.2 (0.7)	3.1	14.5	15.8	**1.3**	15.1 (0.9)	5.9
	1610	6	9	22.8	28.1	5.3	25.7 (1.8)	7.0	19.8	26.0	6.3	23.5 (1.8)	7.8
	1610	7	9	24.7	30.9	6.2	26.5 (2.0)	7.6	19.9	26.9	7.0	23.7 (9.5)	9.5
	1619	4	1	28.8	28.8	0.0	28.8	-	23.9	23.9	0.0	-	-
	1619	6	13	22.4	30.0	7.7	25.1 (2.1)	8.4	13.1	25.3	12.1	18.0 (4.6)	25.7
	1619	7	6	21.3	26.0	4.7	23.1 (2.1)	9.3	12.0	21.5	9.4	15.5 (3.4)	22.0
	1619	8	3	22.8	27.8	4.9	24.7 (2.7)	10.7	17.6	26.5	9.0	20.6 (5.2)	25.1
	411	2	1	16.4	16.4	0.0	16.4	-	13.1	13.1	0.0	-	-
	411	5	3	16.3	19.8	3.5	18.0 (1.8)	9.7	13.2	20.8	7.6	15.8 (4.3)	27.5
	411	6	3	19.2	20.7	1.5	19.7 (0.8)	4.2	13.3	14.2	0.9	13.8 (0.5)	3.4
	411	7	4	17.2	18.8	1.6	18.0 (0.7)	3.7	11.5	17.3	5.8	13.4 (2.7)	19.8
	411	8	5	16.2	18.9	2.7	17.5 (1.1)	6.5	9.6	16.2	6.6	13.1 (2.4)	18.5
	511	4	1	21.0	21.0	0.0	21.0	-	24.0	24.0	0.0	-	-
	511	5	4	13.1	22.0	8.9	18.4 (4.1)	22.0	11.1	23.0	11.9	18.3 (5.3)	28.9
	511	6	5	17.4	25.0	7.6	20.4 (3.0)	14.6	14.2	17.1	2.9	15.6 (1.1)	7.2
SW_GP	511	7	5	18.6	24.3	5.7	20.9 (2.4)	11.3	14.3	22.1	7.8	16.8 (3.2)	18.8
	532	2	2	16.3	20.4	4.1	18.4 (2.9)	15.8	23.8	26.5	2.7	25.2 (1.9)	7.7
	532	4	2	18.8	18.9	**0.1**	18.9 (0.1)	0.4	26.5	26.8	**0.4**	26.6 (0.3)	1.0
	532	5	3	18.7	20.0	1.3	19.3 (0.7)	3.4	16.0	23.4	7.4	20.5 (3.9)	19.2
	532	6	3	17.8	23.0	5.2	20.1 (2.6)	13.0	17.4	23.1	5.6	20.1 (2.8)	14.0
	532	7	4	19.8	22.9	3.1	21.1 (1.3)	6.2	15.9	19.4	3.4	17.8 (1.4)	7.9
	532	8	4	18.0	21.3	3.3	19.4 (1.4)	7.3	18.3	20.7	2.4	19.8 (1.0)	5.3
	639	4	4	14.7	27.7	**13.0**	20.1 (6.3)	31.5	12.7	35.0	22.3	20.9 (9.7)	46.6
	639	5	5	19.9	23.8	4.0	22.7 (1.6)	7.1	13.1	22.9	9.8	17.5 (3.6)	20.9
	639	6	4	21.9	27.7	5.8	25.0 (3.0)	11.9	21.1	28.5	7.4	26.0 (3.3)	12.7
	639	7	3	22.6	23.8	1.2	23.1 (0.6)	2.7	18.3	23.3	5.0	20.8 (2.5)	12.0
	1454	5	3	23.8	26.7	2.9	25.2 (1.5)	5.8	15.8	33.9	18.1	25.6 (9.1)	35.7
	1454	6	7	21.4	30.4	9.0	24.5 (3.2)	13.1	11.9	23.4	11.5	18.1 (4.3)	23.9
	1454	7	6	20.0	29.5	9.4	24.7 (4.0)	16.2	12.9	21.5	8.6	16.6 (3.2)	19.4
	1454	8	2	23.1	24.7	1.6	23.9 (1.1)	4.7	13.8	17.0	3.3	15.4 (2.3)	15.0
	1494	4	2	17.9	18.8	0.9	18.4 (0.6)	3.3	19.0	19.4	0.4	19.2 (0.3)	1.3
	1494	5	7	23.2	31.2	8.0	27.4 (3.1)	11.4	13.8	39.4	25.6	29.4 (10.3)	35.0
	1494	6	10	22.1	31.7	9.6	27.2 (3.7)	13.8	10.9	37.2	26.3	26.5 (8.5)	32.2
	1494	7	2	23.3	25.7	2.4	24.5 (1.7)	6.9	20.9	25.3	4.3	23.1 (3.1)	13.3
	1598	3	2	30.4	30.9	0.5	30.7 (0.4)	1.2	31.3	34.3	3.0	32.8 (2.1)	6.5
	1598	4	2	24.7	26.1	1.5	25.4 (1.0)	4.1	13.6	14.0	0.5	13.8 (0.3)	2.4
	1598	5	4	26.1	31.5	5.4	29.0 (2.7)	9.2	23.3	34.1	10.8	29.2 (5.2)	17.8
SW_LLB	1598	6	6	25.8	31.1	5.3	28.8 (1.9)	6.6	21.3	33.8	12.4	27.7 (4.9)	17.6
	1598	7	6	21.1	30.3	9.2	26.5 (3.4)	12.9	26.3	40.7	14.4	31.8 (5.8)	18.1
	1598	8	1	23.8	23.8	0.0	23.8	-	11.6	11.6	0.0	-	-
	1598	9	1	32.3	32.3	0.0	32.3	-	30.6	30.6	0.0	-	-
	1600	4	2	28.3	29.0	0.6	28.7 (0.4)	1.6	26.3	33.4	7.2	29.8 (5.1)	16.9
	1600	5	7	24.6	31.5	6.8	28.5 (2.6)	9.0	16.0	43.3	**27.2**	29.8 (9.4)	31.7
	1600	6	4	23.6	30.6	7.0	27.1 (2.9)	10.8	17.0	33.7	16.6	23.2 (7.4)	31.8
	1600	7	5	22.3	30.1	7.9	27.1 (2.9)	10.8	20.0	32.5	12.5	28.0 (4.8)	17.0
	1676	1	2	15.2	15.2	0.0	15.2	-	23.7	25.7	2.0	24.7 (1.4)	5.6
	1676	3	2	30.6	30.6	0.0	30.6	-	26.8	31.1	4.4	28.9 (3.1)	10.7
	1676	6	10	25.7	35.0	9.3	31.0 (2.9)	9.4	20.7	44.0	23.2	33.9 (7.5)	22.2
	1676	7	7	22.1	34.6	12.4	27.4 (4.4)	16.1	18.2	40.5	22.3	28.3 (7.7)	27.4

Table 3.8: Stratum canopy cover, minimum, maximum, mean, standard deviation, coefficient of variation for density (sph), breast height age (yr), and site index (m) by polygon stratum for all study polygons

				DENSITY (sph)					SI (m)					BH_AGE (yrs)				
Population	Polygon	CC	N (plots)	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV	Min	Max	Range	Mean (Std)	CV
	97	6	7	267	1367	1100	786 (429)	54.5	18.8	27.0	8.2	22.3 (2.9)	13.1	58	70	13	64 (4.4)	6.9
	97	7	6	700	1333	633	978 (271)	27.8	17.3	21.7	4.4	19.9 (2.3)	11.5	63	82	20	69 (11)	15.8
	97	8	2	667	1367	700	1017 (495)	48.7	19.7	21.9	2.2	20.8 (1.6)	7.5	57	78	21	68 (14.8)	22.0
	97	9	5	567	2067	1500	1407 (582)	41.4	18.9	27.7	8.7	23.0 (3.3)	14.2	56	74	18	66 (6.6)	9.9
	103	3	2	333	533	200	433 (141)	32.6	23.4	23.4	0.0	23.4	-	73	73	0	74	-
	103	4	2	367	400	33	383 (24)	6.1	13.8	13.9	0.1	13.8 (0.1)	0.4	72	72	1	72 (0.4)	0.5
	103	5	2	733	733	0	733	0.0	19.4	21.8	2.4	20.6 (1.7)	8.2	54	74	20	64 (13.8)	21.6
	103	6	2	1233	1400	167	1317 (118)	9.0	22.3	22.3	0.0	22.3	-	68	68	0	68	-
	103	7	4	500	1233	733	725 (344)	47.4	18.3	20.3	2.0	19.3 (1.4)	7.5	62	64	2	63 (1.6)	2.6
	103	8	8	367	1033	667	737 (265)	36.0	19.4	24.7	5.3	22.2 (1.8)	8.2	64	90	26	72 (9.5)	13.2
	103	9	2	967	1767	800	1367 (566)	41.4	22.1	23.8	1.6	22.9 (1.1)	5.0	53	73	20	63 (14.1)	22.6
	124	7	3	433	667	233	544 (117)	21.5	-	-	-	-	-	-	-	-	-	-
	124	8	8	233	900	667	579 (213)	36.8	21.1	25.4	4.3	23.0 (1.7)	7.2	69	86	17	77 (6.8)	8.9
	261	1	1	200	200	0	200	-	-	-	-	-	-	-	-	-	-	-
	261	2	1	267	267	0	267	-	27.0	27.0	0.0	27.0	-	56	56	0	56	-
AW_GP	261	3	2	367	467	100	417 (71)	17.0	25.1	27.0	1.8	26.1 (1.3)	4.9	63	71	9	67 (6.0)	9.0
	261	6	5	433	767	333	580 (122)	21.0	19.7	25.9	6.3	21.9 (2.4)	10.8	39	81	42	64 (15.9)	24.6
	261	7	7	433	967	533	724 (221)	30.5	22.0	26.4	4.4	23.6 (1.9)	8.1	54	71	17	65 (7.5)	11.6
	289	1	1	2367	2367	0	2367	-	-	-	-	-	-	-	-	-	-	-
	289	3	2	400	533	133	467 (94)	20.2	19.8	22.6	2.8	21.2 (2.0)	9.5	80	131	52	105 (36.4)	34.6
	289	4	2	200	667	467	433 (330)	76.1	21.4	22.6	1.2	22.0 (0.9)	4.0	56	63	7	60 (4.9)	8.3
	289	5	2	1533	1600	67	1567 (47)	3.0	20.0	20.0	0.0	20.0	-	74	74	0	74	-
	289	6	7	333	1233	900	767 (312)	40.6	13.3	22.1	8.8	19.0 (3.3)	17.7	72	112	40	89 (12.6)	14.1
	289	7	4	733	1167	433	925 (187)	20.3	22.5	24.0	1.5	23.1 (0.7)	3.0	80	88	8	83 (3.4)	4.1
	289	8	5	633	933	300	813 (117)	14.4	20.4	23.8	3.4	22.3 (1.2)	5.6	73	87	14	78 (5.4)	7.0
	506	1	1	200	200	0	200	-	-	-	-	-	-	-	-	-	-	-
	506	2	2	567	700	133	633 (94)	14.9	-	-	-	-	-	-	-	-	-	-
	506	6	4	267	767	500	608 (236)	38.8	18.6	20.6	2.0	19.7 (1.0)	5.1	55	69	14	63 (7.0)	11.2
	506	7	3	467	700	233	600 (120)	20.0	17.5	19.5	1.9	18.2 (1.1)	6.1	63	74	11	69 (5.6)	8.1
	506	8	5	500	1067	567	713 (219)	30.7	17.3	25.4	8.0	20.7 (3.6)	17.3	71	92	21	78 (9.4)	12.0
	506	9	4	500	1500	1000	1008 (445)	44.1	19.5	23.5	4.0	21.4 (2.0)	9.5	36	95	59	61 (30.4)	49.5
	154	1	2	233	1167	933	700 (660)	94.3	-	-	-	-	-	-	-	-	-	-
	154	3	2	1267	3167	1900	2217 (1343)	60.6	-	-	-	-	-	-	-	-	-	-
	154	5	4	1367	2333	967	1883 (434)	23.1	21.2	24.2	3.0	22.8 (1.2)	5.4	48	65	17	58 (7.7)	13.2
	154	6	6	1333	1900	567	1622 (225)	13.9	23.5	24.5	1.0	23.9 (0.5)	2.1	50	60	10	55 (4.5)	8.1
	154	7	2	1500	1967	467	1733 (330)	19.0	23.4	23.4	0.0	23.4	-	48	48	0	48	-
	154	8	4	1033	2633	1600	1967 (673)	34.2	19.5	25.0	5.5	21.8 (2.9)	13.2	54	57	3	56 (1.3)	2.4
	154	9	5	800	2100	1300	1507 (550)	36.8	21.8	24.0	2.2	22.8 (1.1)	5.0	54	65	12	58 (5.2)	8.9
	1412	4	1	1800	1800	0	1800	-	-	-	-	-	-	-	-	-	-	-
	1412	6	3	867	1400	533	1067 (291)	27.2	17.6	25.4	7.8	21.5 (5.5)	25.8	56	59	3	58 (2.1)	3.7
	1412	7	4	833	1500	667	1183 (274)	23.2	20.5	24.3	3.9	22.3 (1.7)	7.6	50	59	9	54 (4.7)	8.6
	1412	8	10	933	2167	1233	1323 (390)	29.5	19.5	26.8	7.3	23.6 (2.3)	9.7	49	62	13	56 (5.5)	9.8
	1430	4	2	1100	2600	1500	1850 (1061)	57.3	23.3	23.8	0.5	23.6 (0.4)	1.6	56	57	1	56 (0.4)	0.6
AW_LLB	1430	5	5	833	1967	1133	1607 (500)	31.1	21.2	24.3	3.1	23.1 (1.6)	7.1	46	61	15	54 (7.6)	14.0
	1430	6	7	367	1400	1033	1029 (341)	33.1	19.1	25.9	6.8	22.7 (2.4)	10.7	43	85	43	56 (14.2)	25.5
	1430	7	3	867	1433	567	1111 (291)	26.2	19.1	24.3	5.2	22.2 (2.7)	12.4	49	57	8	54 (4.4)	8.1
	1431	3	3	333	2633	2300	1578 (1162)	73.6	24.8	24.8	0.0	24.8	-	84	84	0	84	-
	1431	5	5	833	2067	1233	1460 (482)	33.0	22.2	23.6	1.4	22.9 (1.0)	4.4	53	83	30	68 (21.2)	31.2
	1431	6	8	833	2933	2100	1754 (725)	41.3	16.3	23.8	7.5	20.8 (4.0)	19.0	49	73	24	61 (12.0)	19.6
	1431	7	4	1200	1733	533	1442 (252)	17.4	16.9	16.9	0.0	16.9	-	85	85	0	85	-
	1431	8	2	967	1200	233	1083 (165)	15.2	18.8	18.8	0.0	18.8	-	84	84	0	84	-
	1431	9	2	1600	2000	400	1800 (283)	15.7	22.1	22.1	0.0	22.1	-	53	53	0	53	-
	1610	6	9	567	1267	700	822 (221)	26.9	21.6	26.8	5.2	24.5 (1.8)	7.2	40	77	37	56 (10.0)	18.0
	1610	7	9	600	1333	733	926 (251)	27.1	18.9	30.3	11.4	25.2 (3.8)	15.3	49	93	44	64 (12.4)	19.3
	1619	4	1	833	833	0	833	-	25.6	25.6	0.0	25.6	-	79	79	0	79	-
	1619	6	13	700	2400	1700	1426 (628)	44.1	19.5	23.9	4.4	22.0 (1.4)	6.6	63	85	22	71 (7.0)	9.8
	1619	7	6	1333	2100	767	1706 (321)	18.8	15.6	15.6	0.0	15.6	-	83	83	0	83	-
	1619	8	3	767	1300	533	944 (308)	32.6	20.9	21.8	1.0	21.4 (0.7)	3.2	57	84	28	70 (19.4)	27.7
	411	2	1	1533	1533	0	1533	-	-	-	-	-	-	-	-	-	-	-
	411	5	3	1400	2567	1167	2089 (611)	29.3	18.7	23.8	5.1	21.3 (3.6)	16.9	44	46	2	45 (1.4)	3.1
	411	6	3	1933	3267	1333	2389 (760)	31.8	20.6	20.6	0.0	20.6	-	47	47	0	47	-
	411	7	4	1700	3367	1667	2667 (698)	26.2	17.1	20.3	3.2	18.7 (2.2)	12.0	45	55	10	50 (7.1)	14.1
	411	8	5	1933	5400	3467	3067 (1380)	45.0	19.7	21.4	1.7	20.6 (0.8)	4.1	44	49	6	47 (2.8)	6.0
	511	4	1	833	833	0	833	-	27.3	27.3	0.0	27.3	-	37	37	0	37	-
	511	5	4	933	1600	667	1267 (349)	27.5	17.7	17.7	0.0	17.7	-	96	96	0	96	-
SW_GP	511	6	5	1833	2367	533	2100 (201)	9.6	20.9	24.8	4.0	22.8 (2.2)	9.4	38	43	5	41 (2.4)	5.7
	511	7	5	1500	2733	1233	2340 (520)	22.2	16.2	23.1	6.9	21.1 (3.3)	15.5	37	49	12	44 (5.0)	11.4
	532	2	2	533	833	300	683 (212)	31.0	19.3	23.0	3.8	21.2 (2.7)	12.5	43	45	2	44 (1.4)	3.2
	532	4	2	367	467	100	417 (71)	17.0	25.9	25.9	0.0	25.9	-	37	37	0	37	-
	532	5	3	900	2133	1233	1322 (703)	53.1	22.7	25.6	2.9	23.8 (1.6)	6.6	33	40	7	36 (3.3)	9.3
	532	6	3	1033	1833	800	1322 (444)	33.6	23.9	27.2	3.3	25.7 (1.7)	6.6	25	42	17	36 (9.5)	26.5
	532	7	4	1333	2000	667	1633 (287)	17.6	21.2	27.4	6.2	24.8 (2.6)	10.6	37	46	10	41 (4.2)	10.4
	532	8	4	833	1567	733	1275 (314)	24.7	20.6	24.3	3.7	22.6 (1.9)	8.2	33	36	3	35 (1.3)	3.8
	639	4	4	533	2133	1600	1083 (747)	68.9	-	-	-	-	-	-	-	-	-	-
	639	5	5	867	2133	1267	1633 (474)	29.0	13.8	13.8	0.0	13.8	-	126	126	0	126	-
	639	6	4	567	1000	433	700 (202)	28.8	14.9	14.9	0.0	14.9	-	129	129	0	129	-
	639	7	3	1067	1500	433	1256 (222)	17.7	13.8	16.9	3.1	15.3 (2.2)	14.4	92	96	4	94 (2.8)	3.0
	1454	5	3	433	2000	1567	1078 (819)	76.0	17.1	17.1	0.0	17.1	-	97	97	0	97	-
	1454	6	7	733	2300	1567	1443 (514)	35.7	13.9	19.5	5.6	16.2 (2.5)	15.1	75	107	32	94 (14.1)	14.9
	1454	7	6	1267	2300	1033	1783 (467)	26.2	15.9	19.5	3.5	17.7 (2.5)	14.2	85	92	7	89 (4.9)	5.6
	1454	8	2	1733	2467	733	2100 (518)	24.7	16.7	16.7	0.0	16.7	-	78	78	0	78	-
	1494	4	2	300	333	33	317 (24)	7.4	-	-	-	-	-	-	-	-	-	-
	1494	5	7	333	1733	1400	752 (597)	79.3	12.4	22.5	10.1	18.1 (3.7)	20.1	54	149	95	95 (28.0)	29.4
	1494	6	10	400	3533	3133	983 (1004)	102.1	13.0	25.5	12.4	19.1 (3.9)	20.4	71	143	72	101 (22.7)	22.5
	1494	7	2	700	1267	567	983 (401)	40.7	16.1	17.3	1.2	16.7 (0.9)	5.2	86	91	5	88 (3.2)	3.6
	1598	3	2	300	500	200	400 (141)	35.4	20.5	20.5	0.0	20.5		95	95	0	95	-
	1598	4	2	1400	1467	67	1433 (47)	3.3	-	-	-	-	-	-	-	-	-	-
	1598	5	4	233	967	733	500 (321)	64.2	16.3	16.3	0.0	16.3	-	83	83	0	83	-
SW_LLB	1598	6	6	467	900	433	578 (164)	28.4	17.2	21.6	4.4	19.9 (1.9)	9.5	83	109	26	97 (11.6)	11.9
	1598	7	6	167	733	567	428 (209)	48.9	17.2	21.4	4.2	19.3 (3.0)	15.3	99	100	1	100 (0.7)	0.7
	1598	8	1	1933	1933	0	1933	-	-	-	-	-	-	-	-	-	-	-
	1598	9	1	1033	1033	0	1033	-	-	-	-	-	-	-	-	-	-	-
	1600	4	2	433	667	233	550 (165)	30.0	20.7	20.8	0.1	20.8 (0.1)	0.4	73	93	20	83 (14.1)	17.0
	1600	5	7	267	1067	800	586 (353)	60.3	18.3	24.2	5.9	22.0 (2.3)	10.3	72	110	38	90 (13.4)	14.9
	1600	6	4	533	1333	800	942 (372)	39.5	-	-	-	-	-	-	-	-	-	-
	1600	7	5	433	1200	767	727 (295)	40.6	11.7	21.1	9.4	17.5 (4.3)	24.3	76	124	48	106 (18.3)	17.2
	1676	1	2	67	167	100	117 (71)	60.6	-	-	-	-	-	-	-	-	-	-
	1676	3	2	167	267	100	217 (71)	32.6	-	-	-	-	-	-	-	-	-	-
	1676	6	10	133	700	567	407 (200)	49.1	-	-	-	-	-	-	-	-	-	-
	1676	7	7	233	1033	800	657 (246)	37.4	-	-	-	-	-	-	-	-	-	-

Table 3.9: Parameter estimates and statistical information for simple linear models predicting the dependent variable from canopy cover class for pure aspen polygons in Grande Prairie

Dependent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
TVOL	113.603*	31.613**	**<0.01****	**0.16**	140.85	1100.38	111
QMD	25.34	-0.006	0.98	N/A	6.10	403.52	111
BA	15.527**	3.084**	**<0.01****	**0.19**	12.36	560.13	111
DENSITY	446.780**	52.550**	**<0.01****	**0.06**	390.20	1326.58	111
TOPHT	19.913**	0.739**	**<0.01****	**0.13**	3.62	287.56	111
SI	20.609**	0.137	0.460	0.01	2.83	182.03	86
BH_AGE	75.323**	-0.52	0.56	0.00	13.78	453.23	86

* Statistically significant ($\alpha = 0.05$)
* Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.10: Parameter estimates and statistical information for simple linear models predicting the dependent variable from canopy cover class for pure aspen polygons in Lac La Biche

Dependent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
TVOL	159.00**	19.175**	**<0.01****	**0.10**	83.95	1109.56	125
QMD	16.636**	0.232	0.37	0.01	4.39	371.64	125
BA	21.079**	1.709**	**<0.01****	**0.10**	7.70	512.89	125
DENSITY	1431.052**	-7.535	0.82	0.00	572.18	1589.23	125
TOPHT	22.105**	0.267	0.08	0.02	2.55	235.91	125
SI	24.239**	-0.204	0.39	0.01	2.63	166.37	85
BH_AGE	67.086**	-0.969	0.34	0.01	11.45	416.17	85

* Statistically significant ($\alpha = 0.05$)
** Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.11: Parameter estimates and statistical information for simple linear models predicting the dependent variable from canopy cover class for spruce dominated polygons in Grande Prairie

Dependent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
TVOL	200.999**	12.504	0.09	0.04	87.26	582.92	65
QMD	24.777**	-1.087*	**<0.01****	**0.10**	4.81	206.23	65
BA	24.198**	2.277**	**<0.01****	**0.14**	8.64	282.27	65
DENSITY	104.171	269.266**	**<0.01****	**0.21**	791.45	869.57	65
TOPHT	19.621**	0.084	0.74	0.00	3.03	145.94	65
SI	23.173	-0.233	0.570	0.01	3.74	101.92	38
BH_AGE	54.302	-0.708	0.79	0.00	24.52	245.09	38

* Statistically significant ($\alpha = 0.05$)
** Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.12: Parameter estimates and statistical information for simple linear models predicting the dependent variable from canopy cover class for spruce dominated polygons in Lac La Biche

Dependent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
TVOL	100.887	39.208**	**<0.01****	**0.15**	122.20	962.54	100
QMD	29.671**	-0.559	0.52	0.00	8.32	425.34	100
BA	10.094*	4.066**	**<0.01****	**0.22**	10.34	467.35	100
DENSITY	-63.778	153.295**	**<0.01****	**0.10**	608.27	1281.89	100
TOPHT	26.097**	0.175	0.59	0.01	3.85	266.54	98
SI	23.857	-0.874	0.07	0.07	3.16	112.94	48
BH_AGE	83.312	2.099	0.43	0.01	17.89	278.80	48

* Statistically significant ($\alpha = 0.05$)
** Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.13: Parameter estimates and statistical information for simple linear models predicting volume for pure aspen polygons in Grande Prairie

Independent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
QMD	35.854	2.154**	**<0.01****	**0.20**	434.56	1094.63	111
BA	-59.206**	10.634**	**<0.01****	**0.90**	47.90	860.91	111
DENSITY	259.853**	0.077*	**<0.01****	**0.04**	150.28	1114.75	111
TOPHT	-393.165**	28.831**	**<0.01****	**0.53**	104.73	1034.60	111
SI	5.695	16.097**	**<0.01****	**0.10**	139.04	850.75	86
BH_AGE	60.455	4.066**	**<0.01****	**0.15**	135.25	846.01	86
CC	113.604*	31.613**	**<0.01****	**0.16**	140.85	1100.38	111

* Statistically significant ($\alpha = 0.05$)
** Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.14: Parameter estimates and statistical information for simple linear models predicting volume for pure aspen polygons in Lac La Biche

Independent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
QMD	70.929*	11.566**	**<0.01****	**0.33**	72.73	1073.68	125
BA	-38.924	10.031**	**<0.01****	**0.84**	34.99	890.77	125
DENSITY	303.693**	-0.017	0.22	0.01	88.26	1122.04	125
TOPHT	-141.305*	17.723**	**<0.01****	**0.27**	76.04	1084.79	125
SI	133.364	7.329	**<0.01****	**0.06**	76.68	739.71	86
BH_AGE	194.191	1.761	**0.02**	**0.07**	76.45	739.20	86
CC	159.005**	19.175**	**<0.01****	**0.10**	83.95	1109.56	125

* Statistically significant ($\alpha = 0.05$)
** Statistically highly significant ($\alpha = 0.01$)
Bold represents statistically significant relationships

Table 3.15: Parameter estimates and statistical information for simple linear models predicting volume for spruce dominated polygons in Grande Prairie

Independent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
QMD	131.328**	7.802**	**<0.01****	**0.20**	79.97	571.58	65
BA	-42.098	8.422**	**<0.01****	**0.77**	42.95	490.77	65
DENSITY	288.99	-0.008	0.5	0.01	88.94	585.40	65
TOPHT	-157.970*	21.506**	**<0.01****	**0.53**	61.01	536.41	65
SI	434.415	-6.505	**<0.05**	**0.11**	70.92	325.82	38
BH_AGE	222.287	1.415	**<0.01****	**0.21**	66.45	320.88	38
CC	200.999**	12.504	0.09	0.04	87.26	582.92	65

* Statistically significant (α = 0.05)
** Statistically highly significant (α = 0.01)
Bold represents statistically significant relationships

Table 3.16: Parameter estimates and statistical information for simple linear models predicting volume for spruce dominated polygons in Lac La Biche

Independent Variable	Intercept	Estimate	P value	R square	RMSE	AIC	N
QMD	138.691**	7.174**	**<0.01****	**0.20**	118.32	956.65	100
BA	-38.474**	10.890**	**<0.01****	**0.91**	40.56	742.56	100
DENSITY	348.400**	-0.024	0.25	0.01	41.68	978.04	100
TOPHT	-222.718**	20.519**	**<0.01****	**0.38**	100.28	905.14	98
SI	309.639	2.483	0.53	0.01	87.52	431.26	48
BH_AGE	156.339	2.093	**<0.01****	**0.18**	79.42	421.93	48
CC	100.887	39.208**	**<0.01****	**0.15**	121.85	962.54	100

* Statistically significant (α = 0.05)
** Statistically highly significant (α = 0.01)
Bold represents statistically significant relationship

Table 3.17: Results for models relating volume to various combinations of independent variables at plot level for pure aspen polygons in Grande Prairie

MODELS TESTED	MODELS FOR AW GP	R squared	RMSE	AIC	N	P value
V= F(BA, SI, AGE)	VOL = -373.22562 + 9.73619*BA + 1.87933*AGE + 10.09335*SI	0.93	38.42	631.49	86	<0.01
V = F(BA, CC)	VOL = -59.20558 + 10.63375*BA	0.90	47.90	860.91	111	<0.01
V = F(BA, CC, SI, AGE)	VOL = -59.20558 + 10.63375*BA	0.90	47.90	860.91	111	<0.01
V = F(TOPHT, AGE)	VOL = -393.16498 + 28.83172*TOPHT	0.53	104.73	1034.60	111	<0.01
V = F(TOPHT, CC)	VOL = -417.63374 + 26.67849*TOPHT + 11.90167*CC	0.55	103.01	1031.90	111	<0.01
V = F(TOPHT, CC, AGE)	VOL = - 612.27755+ 28.79582*TOPHT + 15.32734*CC + 1.74515*AGE	0.53	101.31	798.23	86	<0.01
V = F(TOPHT, D_9, AGE)	VOL = -712.68144 + 29.55309*TOPHT + 0.2149*DENSITY_9 + 2.24918*AGE	0.67	85.60	769.25	86	<0.01
V = F(TOPHT, D_15, AGE)	VOL = -609.21522 + 26.23077*TOPHT + 0.32823*DENSITY_15 +1.41267*AGE	0.71	79.72	757.03	86	<0.01
V = F(TOPHT, D, AGE)	VOL = -666.43248 + 30.33294*TOPHT + 0.12331*DENSITY + 2.02257*AGE	0.60	93.89	785.16	86	<0.01
V = F(QMD, SI, AGE)	VOL = -537.52864 + 4.38506*AGE + 5.30755*QMD + 20.33112*SI	0.36	118.51	825.20	86	<0.01
V = F(QMD, CC)	VOL = -171.62168 + 31.6862*CC + 11.25544*QMD	0.36	123.54	1072.23	111	<0.01
V = F(QMD, CC, AGE, SI)	VOL = -728.85263 + 28.38067*CC + 4.14831*AGE + 18.18294*SI + 7.72736*QMD	0.46	109.77	812.97	86	<0.01
V = F(DENSITY, AGE, SI)	VOL = -625.35325 + 5.72238*AGE + 0.11938*DENSITY + 21.88349*SI	0.42	113.16	817.27	86	<0.01
V = F(CC, SI, AGE)	VOL = -650.99289 + 22.45505*CC + 5.37227*AGE + 21.62172*SI	0.39	115.46	820.72	86	<0.01
V = F(SI, AGE)	VOL = -509.65781 + 22.52867*SI + 5.24822*AGE	0.33	120.78	827.51	86	<0.01

BA = plot basal area (m^2); DENSITY_9 = density of trees above 9 cm; CC = canopy cover (10%); DENSITY_15 = density of trees above 15 cm; QMD = quadratic mean diameter (cm) SI = site index (m) VOL = total volume (m^3); DENSITY = density of all trees above breast height TOPHT = top height (m); AGE = breast height age (yr)

Table 3.18: Results for models relating volume to various combinations of independent variables at plot level for pure aspen in Lac La Biche

MODELS TESTED	MODELS FOR AW LLB	R squared	RMSE	AIC	N	P value
V= F(BA, SI, AGE)	VOL = -372.2705 + 9.37263*BA + 1.80204*AGE + 11.04919*SI	0.93	21.05	521.89	85	<0.01
V = F(BA, CC)	VOL = -38.92447 + 10.03136*BA	0.84	34.99	890.77	125	<0.01
V = F(BA, CC, SI, AGE)	VOL = -408.34976 + 9.26509*BA + 4.13157*CC + 1.88922*AGE + 11.37716*SI	0.93	20.57	518.97	85	<0.01
V = F(TOPHT, AGE)	VOL = -141.30485 + 17.72273*TOPHT	0.27	76.04	1084.79	125	<0.01
V = F(TOPHT, CC)	VOL = -198.6876 + 16.40624*TOPHT + 14.12306*CC	0.32	73.29	1076.49	125	<0.01
V = F(TOPHT, CC, AGE)	VOL = -198.6876 + 16.40624*TOPHT + 14.12306*CC	0.32	73.29	1076.49	125	<0.01
V = F(TOPHT, D_9, AGE)	VOL = -375.1011 + 17.94742*TOPHT + 0.12866*DENSITY_9 + 1.88138*AGE	0.37	63.35	709.16	85	<0.01
V = F(TOPHT, D_15, AGE)	VOL = -326.29547 + 13.96859*TOPHT + 0.24544*DENSITY_15 + 2.00127*AGE	0.60	50.73	671.44	85	<0.01
V = F(TOPHT, D, AGE)	VOL = -141.30485 + 17.72273*TOPHT	0.27	76.04	1084.79	125	<0.01
V = F(QMD, SI, AGE)	VOL = 70.92908 + 11.5659*QMD	0.33	72.73	1073.68	125	<0.01
V = F(QMD, CC)	VOL = -23.835 + 16.379*CC + 11.082*QMD	0.41	68.73	1060.51	125	<0.01
V = F(QMD, CC, AGE, SI)	VOL = -23.835 + 16.379*CC + 11.082*QMD	0.41	68.73	1060.51	125	<0.01
V = F(DENSITY, AGE, SI)	VOL = -159.30624 + 2.90418*AGE + 12.39584*SI	0.21	70.75	726.99	85	<0.01
V = F(CC, SI, AGE)	VOL = -276.97268 + 12.61973*CC + 3.13185*AGE + 13.35041*SI	0.25	69.49	724.9	85	<0.01
V = F(SI, AGE)	VOL = -159.30624 + 2.90418*AGE + 12.39584*SI	0.21	70.75	726.99	85	<0.01

BA = plot basal area (m^2); DENSITY_9 = density of trees above 9 cm; CC = canopy cover (10%); DENSITY_15 = density of trees above 15 cm; QMD = quadratic mean diameter (cm) SI = site index (m) VOL = total volume (m^3); DENSITY = density of all trees above breast height TOPHT = top height (m); AGE = breast height age (yr)

Table 3.19: Results for models relating volume to various combinations of independent variables at plot level for spruce dominated polygons in Grande Prairie

MODELS TESTED	MODELS FOR SW GP	R squared	RMSE	AIC	N	P value
V= F(BA, SI, AGE)	VOL = -281.5503 + 8.66807*BA + 1.91782*AGE + 5.91468*SI	0.91	22.76	241.3	38	<0.01
V = F(BA, CC)	VOL = -42.09825 + 8.422*BA	0.77	42.94	490.77	65	<0.01
V = F(BA, CC, SI, AGE)	VOL = -281.5503 + 8.66807*BA + 1.91782*AGE + 5.91468*SI	0.91	22.76	241.3	38	<0.01
V = F(TOPHT, AGE)	VOL = -157.96997 + 21.50559*TOPHT	0.53	61.02	536.41	65	<0.01
V = F(TOPHT, CC)	VOL = -216.60726 + 21.28343*TOPHT + 10.71001*CC	0.57	59.33	533.74	65	<0.01
V = F(TOPHT, CC, AGE)	VOL = -216.60726 + 21.28343*TOPHT + 10.71001*CC	0.57	59.33	533.74	65	<0.01
V = F(TOPHT, D_9, AGE)	VOL = -244.59972 + 20.99971*TOPHT + 0.05762*DENSITY_9 + 0.89882*AGE	0.60	49.04	299.62	38	<0.01
V = F(TOPHT, D_15, AGE)	VOL = -319.69544 + 21.97233*TOPHT + 0.16891*DENSTIY_15 + 0.9773*AGE	0.69	42.70	289.08	38	<0.01
V = F(TOPHT, D, AGE)	VOL = -157.96997 + 21.50559*TOPHT	0.53	61.02	536.41	65	<0.01
V = F(QMD, SI, AGE)	VOL = 222.2869 + 1.41476*AGE	0.21	66.45	320.88	38	<0.01
V = F(QMD, CC)	VOL = -47.37259 + 23.39739*CC + 10.02441*QMD	0.34	73.29	561.21	65	<0.01
V = F(QMD, CC, AGE, SI)	VOL = 222.2869 + 1.41476*AGE	0.21	66.45	320.88	38	<0.01
V = F(DENSITY, AGE, SI)	VOL = 222.2869 + 1.41476*AGE	0.21	66.45	320.88	38	<0.01
V = F(CC, SI, AGE)	VOL = 222.2869 + 1.41476*AGE	0.21	66.45	320.88	38	<0.01
V = F(SI, AGE)	VOL = 222.2869 + 1.41476*AGE	0.21	66.45	320.88	38	<0.01

BA = plot basal area (m^2); DENSITY_9 = density of trees above 9 cm; CC = canopy cover (10%); DENSITY_15 = density of trees above 15 cm; QMD = quadratic mean diameter (cm) SI = site index (m) VOL = total volume (m^3); DENSITY = density of all trees above breast height TOPHT = top height (m); AGE = breast height age (yr)

Table 3.20: Results for models relating volume to various combinations of independent variables at plot level for spruce dominated polygons in Lac La Biche

MODELS TESTED	MODELS FOR SW LLB	R squared	RMSE	AIC	N	P value
V= F(BA, SI, AGE)	VOL = -250.74659 + 9.92113*BA + 1.03743*AGE + 7.57754*SI	0.92	24.92	312.55	48	<0.01
V = F(BA, CC)	VOL = -38.47356 + 10.89033*BA	0.91	40.56	742.56	100	<0.01
V = F(BA, CC, SI, AGE)	VOL = -250.74659 + 9.92113*BA + 1.03743*AGE + 7.57754*SI	0.92	24.92	312.55	48	<0.01
V = F(TOPHT, AGE)	VOL = -207.14271 + 1.6259*AGE + 14.83644*TOPHT	0.41	68.01	407.99	48	<0.01
V = F(TOPHT, CC)	VOL = -379.737 + 20.015*TOPHT + 29.044*CC	0.45	94.34	894.14	98	<0.01
V = F(TOPHT, CC, AGE)	VOL = -207.14271 + 1.6259*AGE + 14.83644*TOPHT	0.41	68.01	905.14	48	<0.01
V = F(TOPHT, D_9, AGE)	VOL = -393.56563 + 19.24159*TOPHT + 0.09642*DENSITY_9 + 1.70616*AGE	0.47	65.45	405.24	48	<0.01
V = F(TOPHT, D_15, AGE)	VOL = -404.61755 + 18.42514*TOPHT + 0.21253*DENSITY_15 + 1.60604*AGE	0.57	59.08	395.38	48	<0.01
V = F(TOPHT, D, AGE)	VOL = -207.14271 + 1.6259*AGE + 14.83644*TOPHT	0.41	68.01	407.99	48	<0.01
V = F(QMD, SI, AGE)	VOL = 138.69131 + 7.17409*QMD	0.20	118.32	956.65	100	<0.01
V = F(QMD, CC)	VOL = -130.43298 + 43.56636*CC + 7.79612*QMD	0.39	103.75	931.36	100	<0.01
V = F(QMD, CC, AGE, SI)	VOL = -130.43298 + 43.56636*CC + 7.79612*QMD	0.39	103.75	931.36	100	<0.01
V = F(DENSITY, AGE, SI)	VOL = -56.36349 + 2.69118*AGE + 8.28516*SI	0.27	76.18	418.89	48	<0.01
V = F(CC, SI, AGE)	VOL = -56.36349 + 2.69118*AGE + 8.28516*SI	0.27	76.18	418.89	48	<0.01
V = F(SI, AGE)	VOL = -56.36349 + 2.69118*AGE + 8.28516*SI	0.27	76.18	418.89	48	<0.01

BA = plot basal area (m^2); DENSITY_9 = density of trees above 9 cm; CC = canopy cover (10%); DENSITY_15 = density of trees above 15 cm; QMD = quadratic mean diameter (cm) SI = site index (m) VOL = total volume (m^3); DENSITY = density of all trees above breast height TOPHT = top height (m); AGE = breast height age (yr)

Table 3.21: Species percent volume, species mean volume, number of plots containing each species, and total number of plots by polygon for pure aspen polygons in Grande Prairie and Lac
La Biche

Population	Polygon	Species	N (plots)	Percent Volume (%)	Mean Vol (m3)	N Total (plots)
AW_GP	97	Aw	10	32.0	95.8	20
	97	Bw	2	0.0	0.1	20
	97	Fb	5	0.0	0.1	20
	97	Pb	19	55.7	166.8	20
	97	Pl	2	3.4	10.1	20
	97	Sw	16	8.8	19.0	20
	103	Aw	19	65.7	197.5	22
	103	Bw	3	0.0	0.5	22
	103	Pb	20	27.5	82.9	22
	103	Pl	1	2.5	7.6	22
	103	Sb	2	2.1	6.5	22
	103	Sw	11	2.2	6.5	22
	124	Aw	7	45.4	148.1	11
	124	Pb	11	53.8	175.6	11
	124	Sw	4	0.8	2.6	11
	261	Aw	11	58.6	195.6	16
	261	Bw	2	0.1	0.3	16
	261	Pb	7	34.8	116.2	16
	261	Sw	2	6.5	21.7	16
	289	Aw	22	95.6	354.7	23
	289	Bw	13	1.2	4.4	23
	289	Pb	11	3.1	11.4	23
	289	Sw	8	0.2	0.6	23
	506	Aw	9	32.6	95.9	19
	506	Bw	2	0.3	1.0	19
	506	Pb	14	61.0	179.6	19
	506	Pl	1	4.0	11.9	19
	506	Sb	1	1.5	4.4	19
	506	Sw	6	0.6	1.8	19
AW_LLB	154	Aw	24	77.1	195.3	25
	154	Bw	23	6.8	17.2	25
	154	Fb	23	1.0	2.5	25
	154	Pb	12	10.0	25.4	25
	154	Sw	24	5.1	13.0	25
	1412	Aw	18	85.8	234.2	18
	1412	Pb	14	12.2	33.2	18
	1412	Sw	9	2.0	5.4	18
	1430	Aw	17	64.6	171.4	17
	1430	Bw	13	4.9	13.0	17
	1430	Fb	7	4.7	12.6	17
	1430	Pb	11	7.1	18.8	17
	1430	Sw	16	18.7	49.7	17
	1431	Aw	24	90.8	217.4	24
	1431	Bw	11	0.5	1.1	24
	1431	Pb	16	5.5	13.2	24
	1431	Sw	18	3.3	7.8	24
	1610	Aw	15	87.0	81.5	22
	1610	Pb	5	13.0	0.4	22
	1610	Sw	9	0.0	13.3	22
	1619	Aw	22	87.5	232.8	22
	1619	Bw	9	1.1	34.8	18
	1619	Pb	2	0.9	0.5	18
	1619	Sw	13	10.5	81.7	18

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.22: Species percent volume, species mean volume, number of plots containing each species, and total number of plots by polygon for spruce dominated polygons in Grande Prairie and Lac La Biche

Population	Polygon	Species	N (plots)	Percent Volume (%)	Mean Vol (m3)	N Total (plots)
SW_GP	411	Aw	2	2.5	5.7	16
SW_GP	411	Bw	11	2.9	6.5	16
SW_GP	411	Fb	16	8.6	19.7	16
SW_GP	411	Pb	10	4.8	10.9	16
SW_GP	411	Pl	10	12.1	27.6	16
SW_GP	411	Sw	16	69.1	157.5	16
SW_GP	511	Aw	3	3.5	10.7	15
SW_GP	511	Bw	11	1.0	3.1	15
SW_GP	511	Fb	8	0.9	2.7	15
SW_GP	511	Pb	7	11.0	33.6	15
SW_GP	511	Pl	4	5.7	17.5	15
SW_GP	511	Sw	15	77.9	238.7	15
SW_GP	532	Aw	2	0.2	0.5	18
SW_GP	532	Bw	13	3.6	9.1	18
SW_GP	532	Fb	10	1.2	3.1	18
SW_GP	532	Pb	9	9.1	23.2	18
SW_GP	532	Pl	4	3.3	8.4	18
SW_GP	532	Sw	18	82.6	210.7	18
SW_GP	639	Fb	14	8.8	27.6	16
SW_GP	639	Pl	14	48.3	151.5	16
SW_GP	639	Sw	15	42.9	134.7	16
SW_LLB	1454	Aw	13	12.5	39.7	18
SW_LLB	1454	Bw	11	2.0	6.2	18
SW_LLB	1454	Fb	18	24.0	76.1	18
SW_LLB	1454	Pb	7	5.6	17.9	18
SW_LLB	1454	Pl	1	4.1	13.1	18
SW_LLB	1454	Sw	17	51.8	164.3	18
SW_LLB	1494	Aw	18	20.2	239.1	18
SW_LLB	1494	Bw	18	0.6	322.7	18
SW_LLB	1494	Pb	12	15.9	48.0	18
SW_LLB	1494	Sw	1	63.4	0.0	18
SW_LLB	1598	Aw	14	24.8	64.9	21
SW_LLB	1598	Bw	8	0.1	1.9	21
SW_LLB	1598	Pb	14	4.0	51.1	21
SW_LLB	1598	Sw	20	71.0	204.1	21
SW_LLB	1600	Aw	23	9.8	260.5	23
SW_LLB	1600	Bw	17	0.1	3.3	23
SW_LLB	1600	Pb	2	22.9	2.7	23
SW_LLB	1600	Sw	22	67.1	31.2	23
SW_LLB	1676	Aw	11	13.1	42.0	21
SW_LLB	1676	Bw	8	0.5	1.7	21
SW_LLB	1676	Pb	13	12.9	41.2	21
SW_LLB	1676	Sw	21	73.5	235.7	21

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Table 3.23: Stand age based on year of origin and mean, minimum, maximum, and standard deviation for breast height age (yr) for all the study polygons

	Stand	N (plots)	AVI Origin (year)	AVI Stand Age (years)	Breast Height Age mean (min-max)	StdDev (years)
AW_GP	97	16	1930	77	66 (56-82)	7
	103	17	1920	87	69 (53-90)	9
	124	7	1930	77	77 (69-86)	7
	261	12	1920	87	64 (39-81)	11
	289	21	1910	97	83 (56-131)	16
	506	13	1930	77	69 (36-95)	16
AW_LLB	154	16	1930	77	56 (48-65)	5
	1412	13	1930	77	56 (49-62)	5
	1430	15	1920	87	55 (43-85)	10
	1431	9	1910	97	70 (49-85)	15
	1610	18	1942	65	60 (40-93)	12
	1619	14	1920	87	72 (57-85)	9
SW_GP	411	8	1910	97	47 (44-55)	4
	511	10	1920	87	47 (37-96)	18
	532	16	1920	87	38 (25-46)	5
	639	4	1900	107	111 (92-129)	19
SW_LLB	1454	8	1880	127	91 (75-107)	11
	1494	19	1870	137	98 (54-149)	23
	1598	8	1900	107	96 (83-109)	9
	1600	13	1880	127	95 (72-124)	17

AW_GP = Pure aspen polygons from Grande Prairie
SW_GP = Spruce dominated polygons from Grande Prarie
AW_LLB = Pure aspen polygons from Lac La Biche
SW_LLB = Spruce dominated polygons from Lac La Biche

Figure 3.1: Relationship between three fragmentation indices and volumes for all polygons together

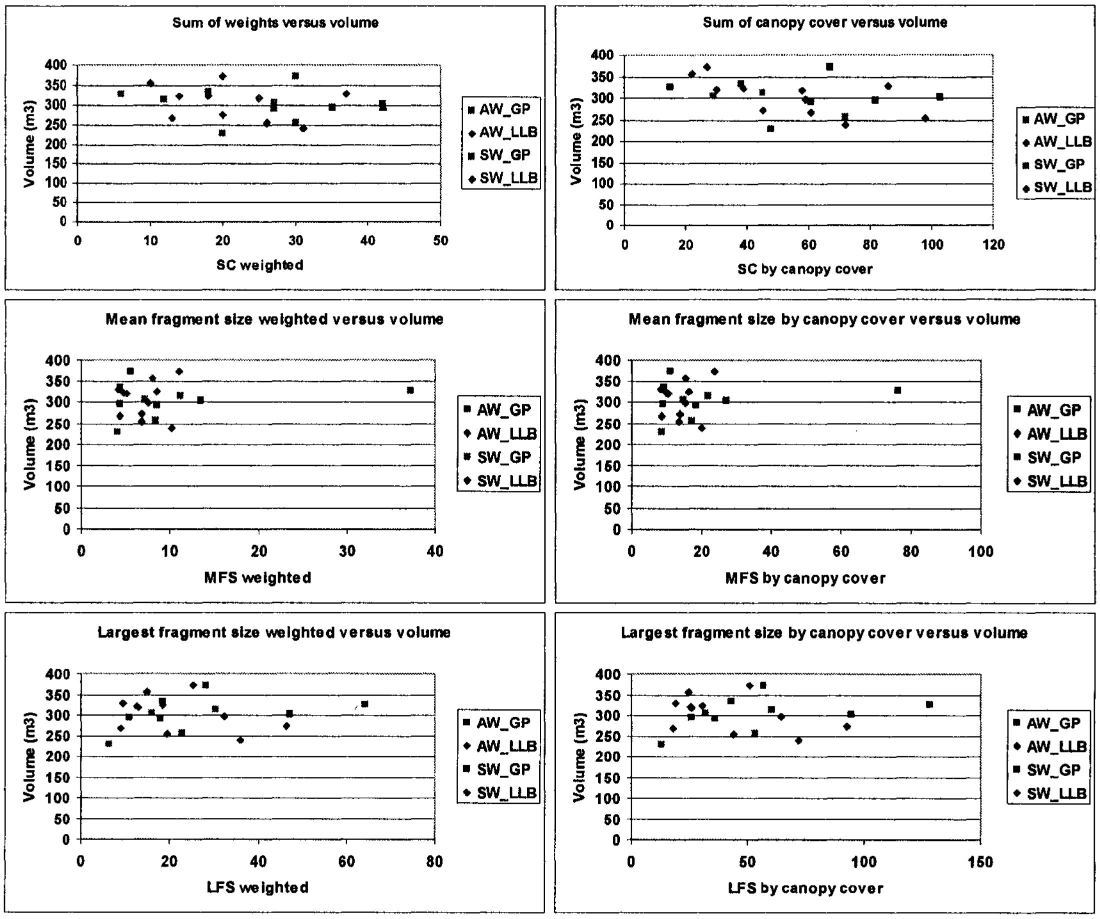


Figure 3.2: Percent species volume and mean stand volume by species and populations

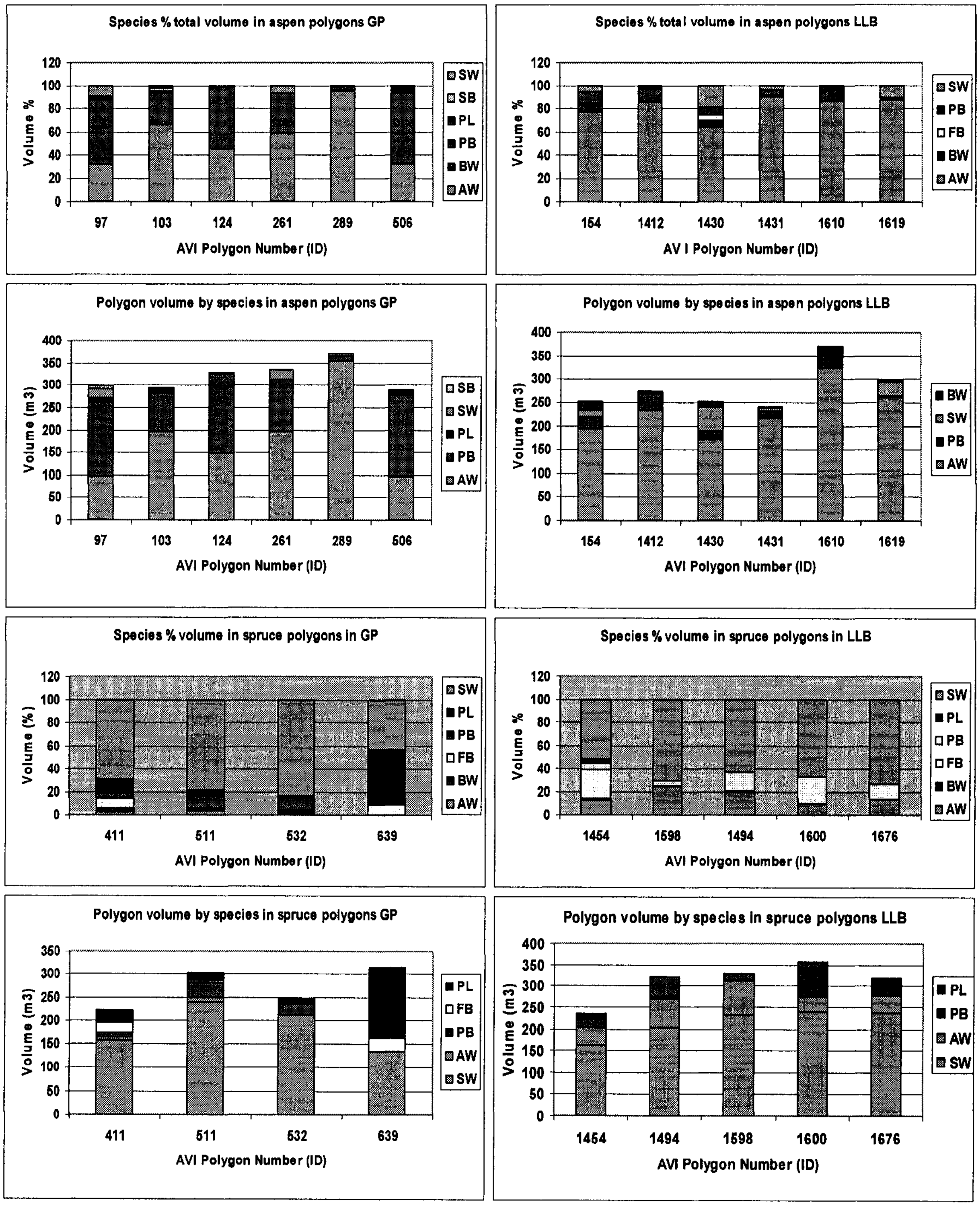
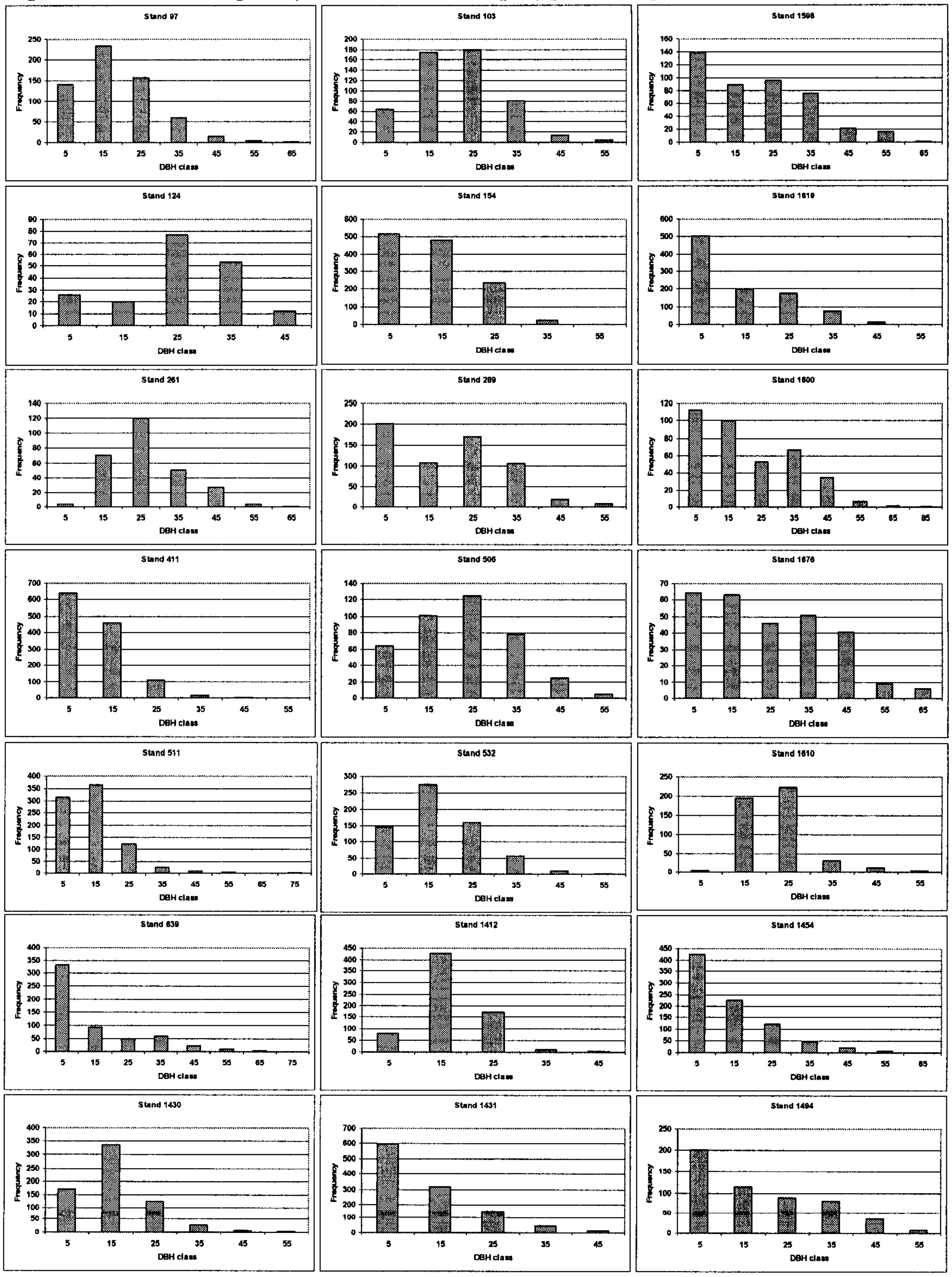


Figure 3.3: DBH frequency distribution – all polygons all species combined



Chapter 4. General Conclusions

In its first part, this study compared the predictive ability of three growth and yield models developed in two provinces, Alberta and Saskatchewan, against actual re-measurements. Since models represent simplifications of real stand dynamics the potential user of any model needs to understand model constraints and the methodology used to develop each particular model. It was clear from this study that each model has a certain range of use.

For example, the Provincial Yield Curves can be used in determining landscape level yield. However the model is not appropriate for calculating yield in stands under different silvicultural treatments, or stands in the break-up stage, or stands that manifest transition between strata.

The Fleweling model is the model that has the smallest deviations between predicted and measured values across all species. However, the model is not designed to predict lower stocked stands since the major driver, the basal area increment function, represents the PSP trajectory and any stand is adjusted towards this yield curve. At the same time, differences in stand productivity only marginally affect the final outcome since only quadratic mean diameter increment varies with site index. The model is limited by design to predicting PSP yields.

MGM has a larger range of predictions and can model a wide range of stand and individual tree characteristics. However, the model is sensitive to the quality of inputs, (particularly breast height age, and site index), in order to model the correct stand trajectory.

Understanding the models' abilities cannot be done just by analyzing the deviation plots. It is necessary to investigate and relate the predictions to the datasets and modeling methodologies used in the models' development, as well as to the dataset and scenarios used in the evaluation process.

The difference between yield in a permanent sample plot and the mean landscape level yield became apparent when PSP re-measurements were compared to the Provincial

Yield Curves predictions. The major sources for the difference were considered to be a scale difference since a PSP represents a small portion of a particular stand while the model's prediction represents the mean landscape level yield, and a sampling procedure difference between the TSP and PSP data.

In Chapter 3 the possibility of categorizing similar AVI map type polygons based on an index that quantifies stocking expressed in 10% units of canopy cover was investigated. The weak relationship between plot volume and canopy cover prevented the further development of an index of fragmentation that would have constituted a first estimate of Volume Loss Factor.

The weak relationship is explained by the great variability around the mean for all stand characteristics found in our four study populations and by the fact that canopy cover cannot describe volume variation in uneven-aged polygons. Many of the plots sampled in this study showed an inverse J-shaped distribution indicative of uneven-aged stands, and many of the plots had mixed species composition. In these mixed and uneven-aged, polygons, site index and mean age become less relevant (Huang and Titus, 1993; Avery and Burkhart, 1994).

The polygon map call was in many cases inaccurate in characterizing the polygons, with height, canopy cover, and species composition being more variable than expected. However, AVI is a useful tool for stratifying the forested area in the development of yield curves because the large number of random temporary sample plots was sufficient to describe the mean stratum yield across a range of ages regardless of the variability within AVI polygons. A random TSP sample of sufficient size was capable of capturing the actual landscape mean yield in a stratum. This accepted variability for the purposes of yield curve development becomes an impediment when modeling with growth and yield models. It is important that growth and yield models are applied to "biological" stands that match the variability of the dataset used to develop the model functions and conform to the model assumptions (i.e. even-age, similar productivity). Whenever these assumptions are not met and predictions are used to describe heterogeneous polygons (age, productivity, species composition), the model predictions of the actual yield become less reliable.

The preferred approach for model use (i.e. MGM) would be to predict yield in homogeneous fragments of polygons that meet the model assumptions, even-age and similar productivity. This would require more sensitivity in the delineation process of the AVI polygons. The large structural variability within these study polygons did not permit us to classify the polygons based on canopy cover fragmentation. However, top height was identified as a variable that better explained volume than canopy cover. At the same time individual tree height can be measured from large scale aerial photographs (Hall et al., 2001) and polygon height is a variable that already exists in AVI. Delineating less variable polygons can be achieved if the accuracy in determining canopy cover and polygon height is increased.

The young post-harvest polygons conform better conforming to these criteria since they are even-aged and the reforested area is clearly delineated from other stand types. These polygons do have less potential for mixing together areas with different history as do the natural polygons. Based on these characteristics these polygons would be better candidates for modeling than mature natural post-fire origin polygons.

This study showed that using growth and yield models needs to be done by an informed user who understands how the model being used functions. Good results from validation do not always indicate that the model is ready for use at the landscape level, unless the validation was produced with a random sample of the landscape. The biases in the data used to fit the model relationships as well as in the database used for the validation need to be scrutinized. At the same time, polygons with similar AVI map calls have embedded within them larger variability in species composition, age, height, and quadratic mean diameter than it was expected. This makes it difficult to model yield in natural polygons using growth and yield models since polygon structure does not always correspond to the model assumptions (even-age, similar productivity, similar species composition).

Further research is required to explore the behavior of growth and yield models, in particular the Mixedwood Growth Model, and understand the range of predictions they provide. The impact of erroneous input data (site index, age, species composition) also requires further investigation. At the same time, the AVI needs to be scrutinized and the applicability of the information from this management system in the context of using growth and yield models needs to be assessed. The accuracy of the information is critical for obtaining sound predictions, otherwise the uncertainty from the management system coupled with the inherent bias embedded within models is transferred to the predictions, making them less reliable.

References

Avery, T.E., and Burkart, H.E.1994. Forest Measurements, 4th ed., McGraw-Hill, New York, USA, pp 269.

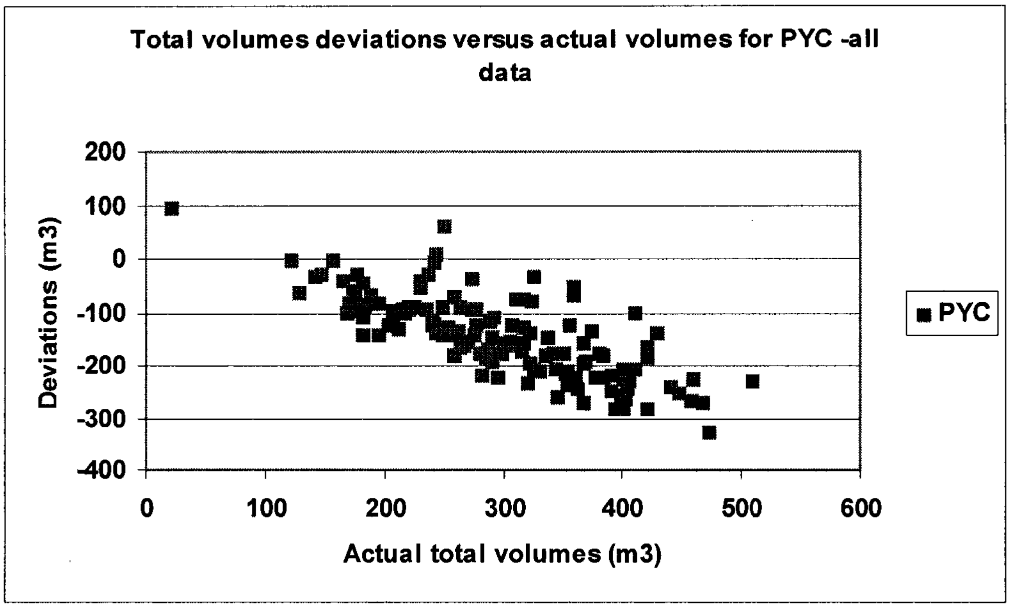
Huang, S., and Titus, S.J. 1993. An index of site productivity for uneven-aged or mixed species stands. Can. J. For. Res. 23: 558-562.

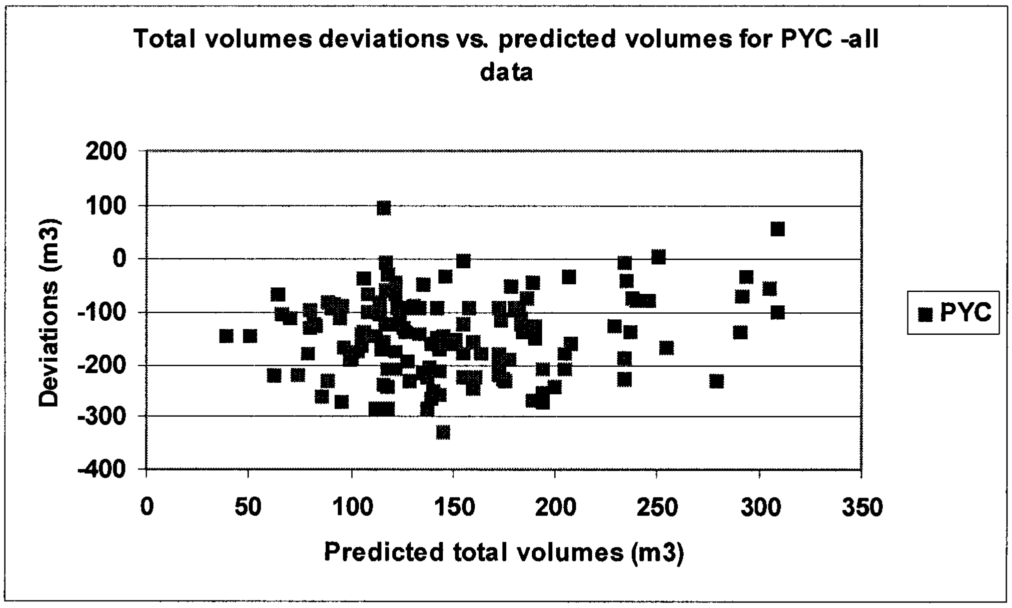
Hall, R.J., Wang, Y., and Morgan, D.J. 2001. Estimating tree diameter and volume with a taper model and large-scale photo measurements. North. J. of Appl. For. 18: 110-118.

APPENDICES

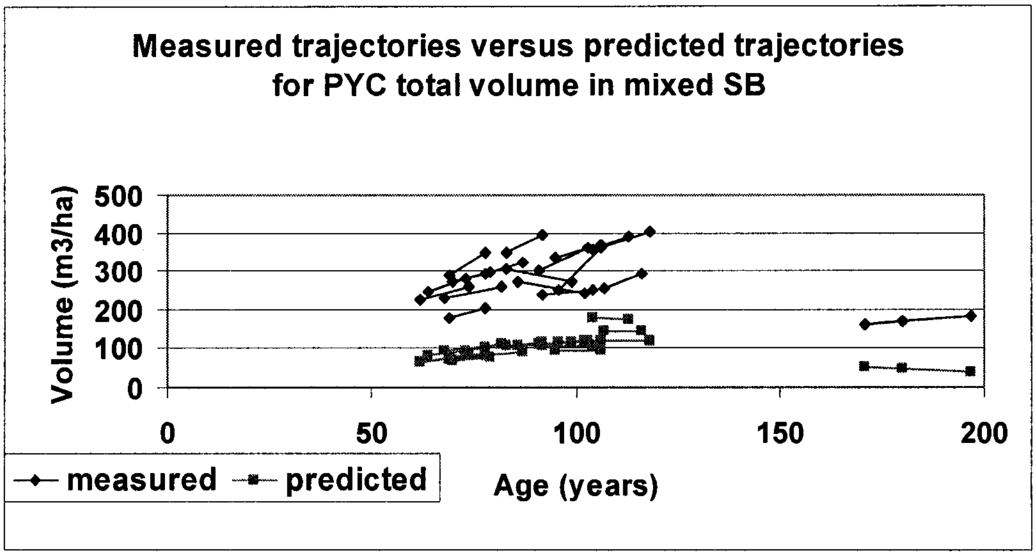
Appendix I. Deviations versus predicted and deviations versus actual for all stand characteristics and all three models

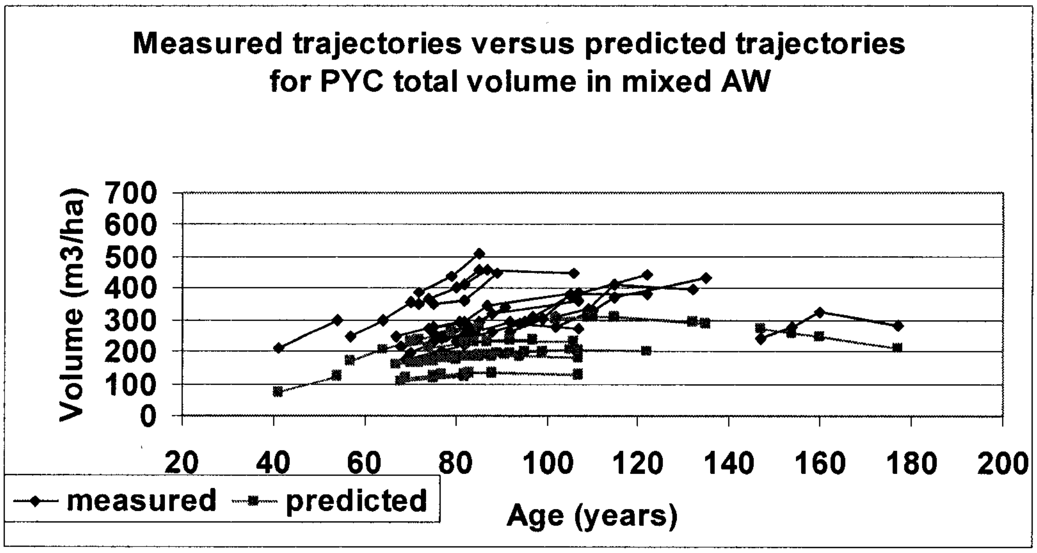
Appendix I.1 Provincial Yield Curves total volume deviations (m^3) against actual total volumes (m^3) and total volume deviations (m^3) against predicted total volumes (m^3) for all species combined.



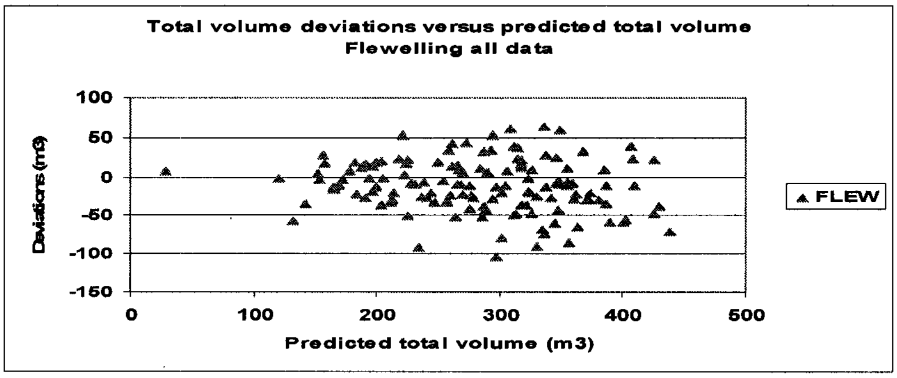


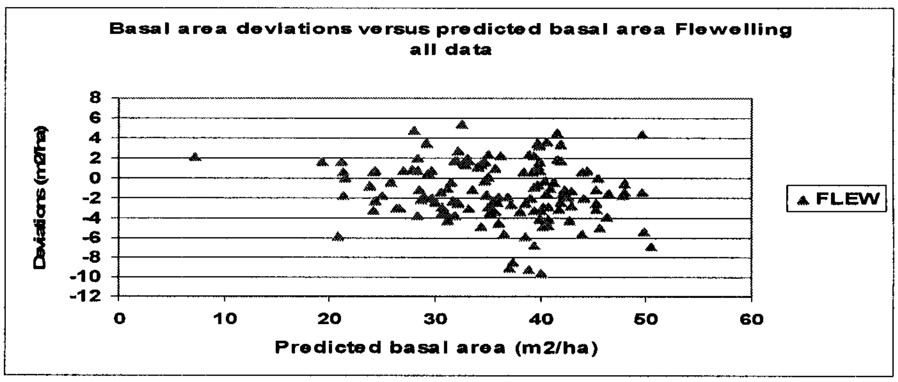
Appendix I.2 Provincial Yield Curves predicted trends versus actual trends for total volume in mixed black spruce species association

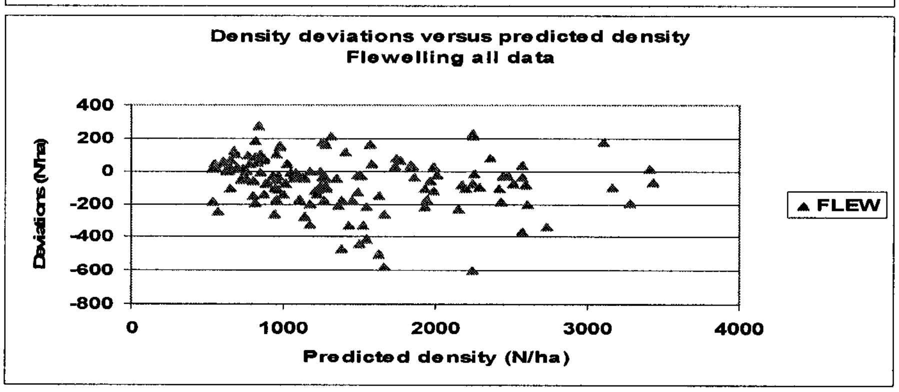


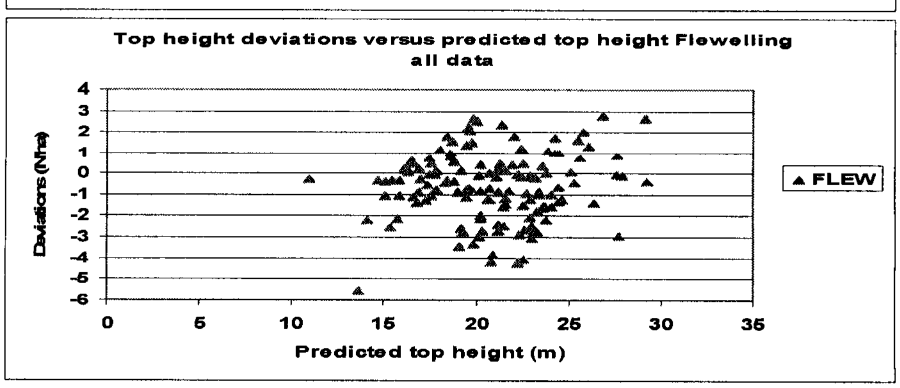


Appendix I.3 Flewelling total volume deviations (m^3) against predicted total volume (m^3), basal area deviations (m^2) against predicted basal area (m^2), density deviations (N/ha) against predicted density (N/ha), and top height deviations (m) against predicted top height (m) for all species combined.

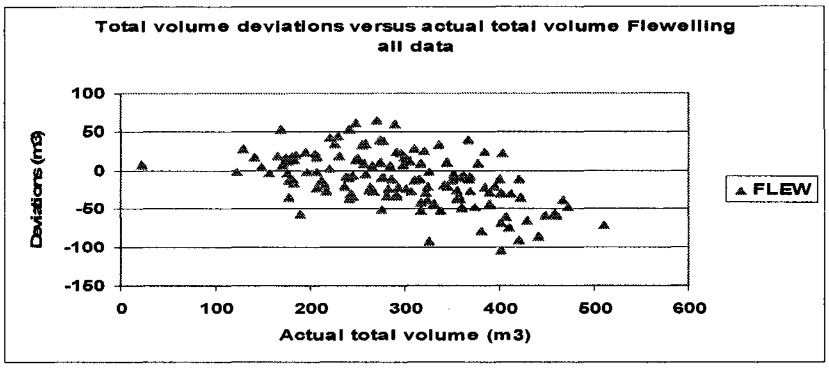


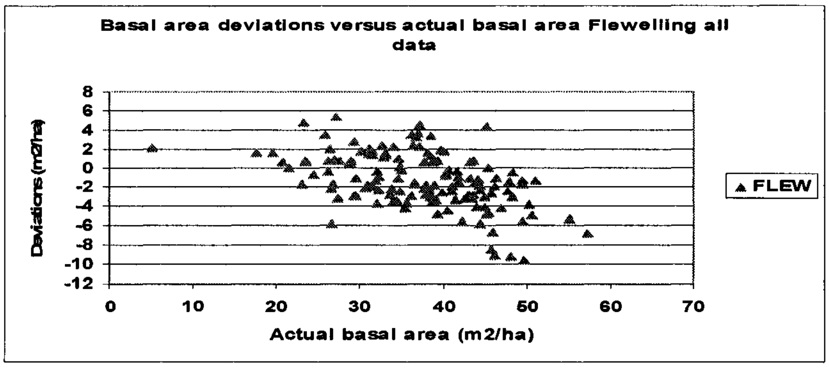


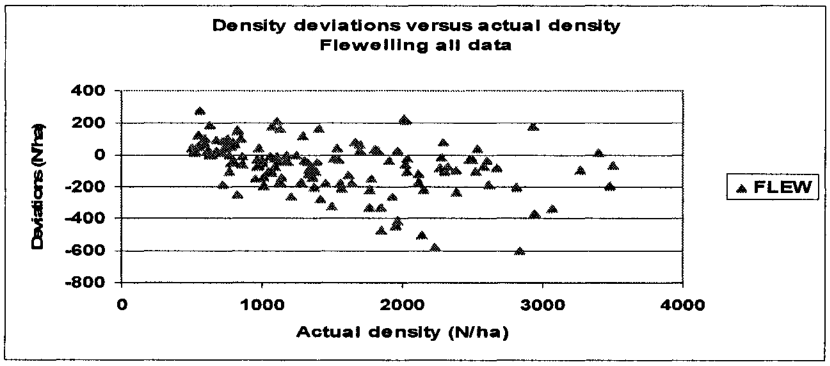


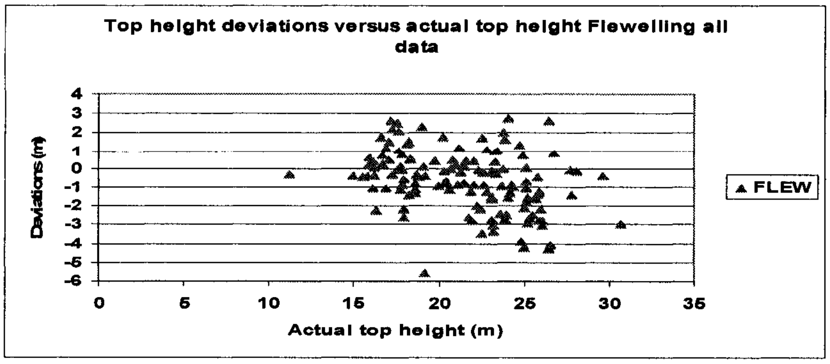


Appendix I.4 Flewelling total volume deviations (m^3) against actual total volume (m^3), basal area deviations (m^2) against actual basal area (m^2), density deviations (N/ha) against actual density (N/ha), and top height deviations (m) against actual top height (m) for all species combined.

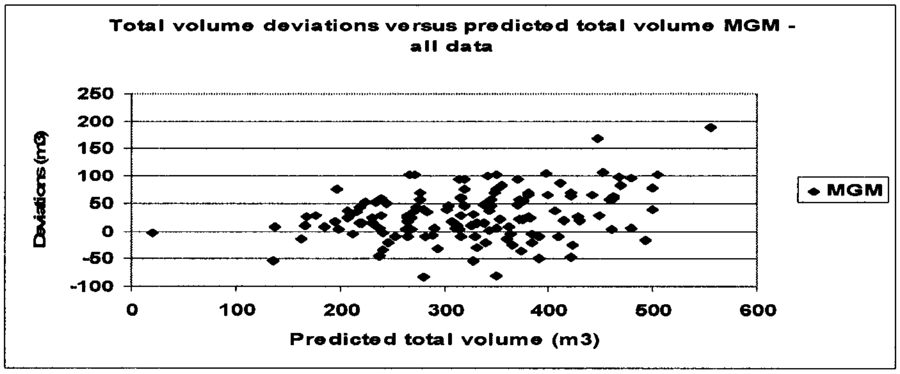


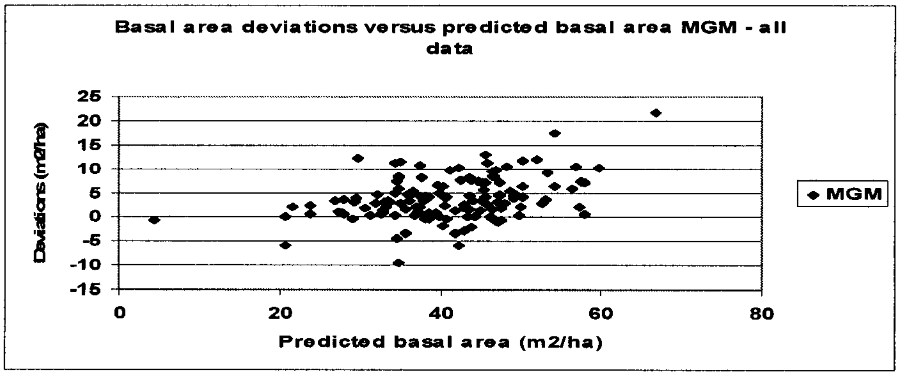


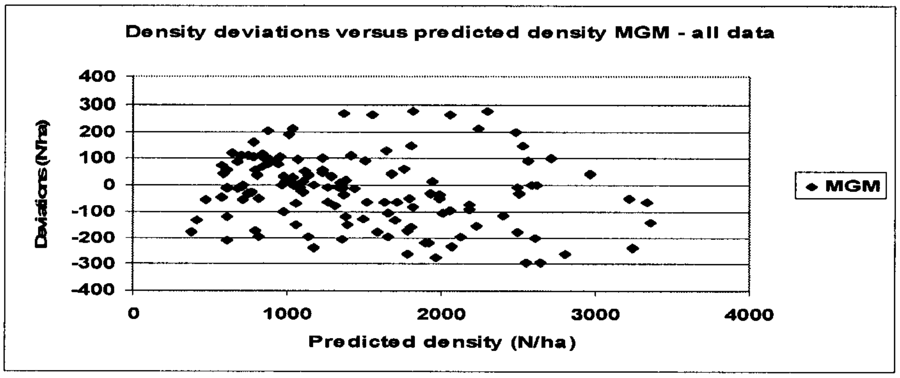


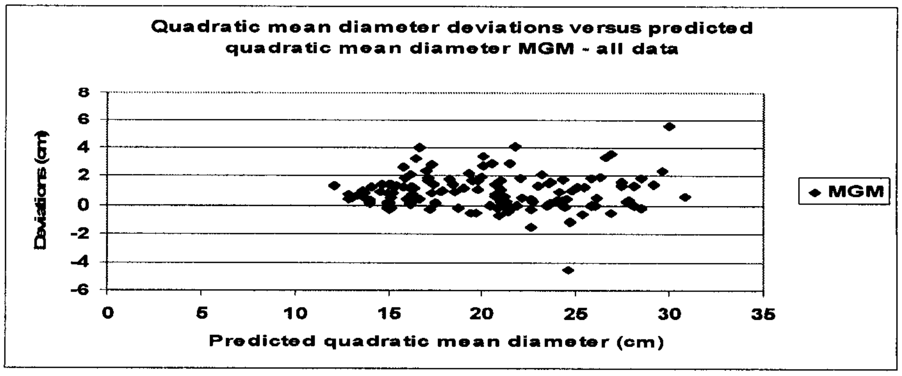


Appendix I.5 MGM total volume deviations (m^3) against predicted total volume (m^3), basal area deviations (m^2) against predicted basal area (m^2), density deviations (N/ha) against predicted density (N/ha), and quadratic mean diameter deviations (cm) against predicted quadratic mean diameter (cm) for all species combined.

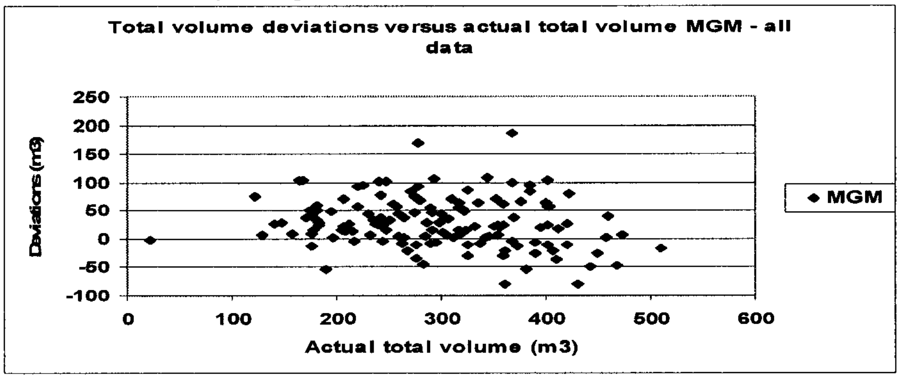


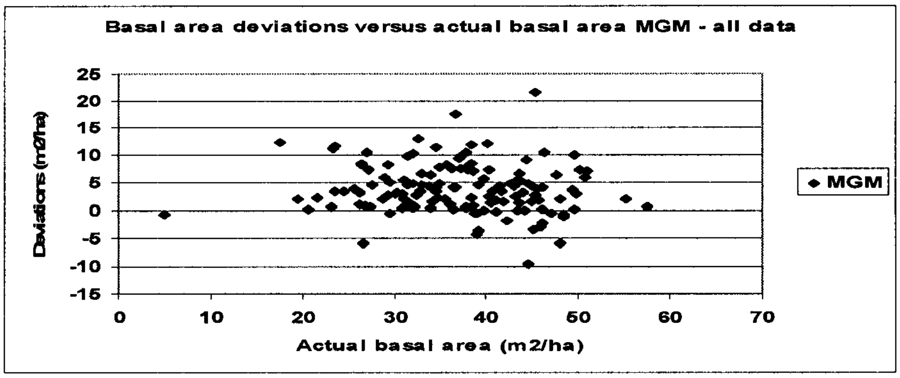


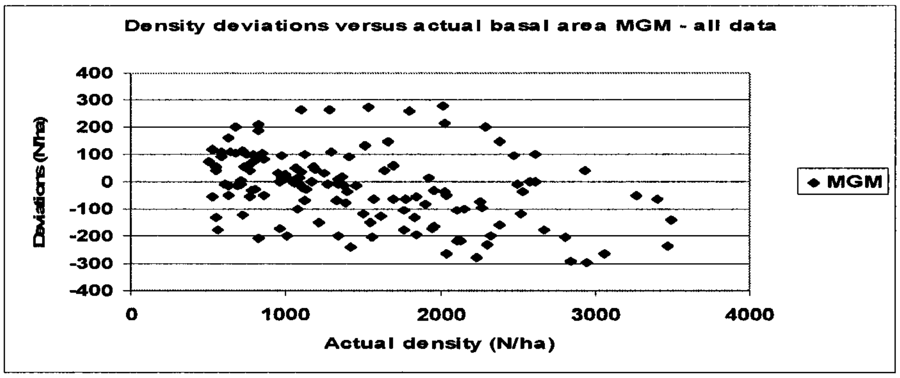


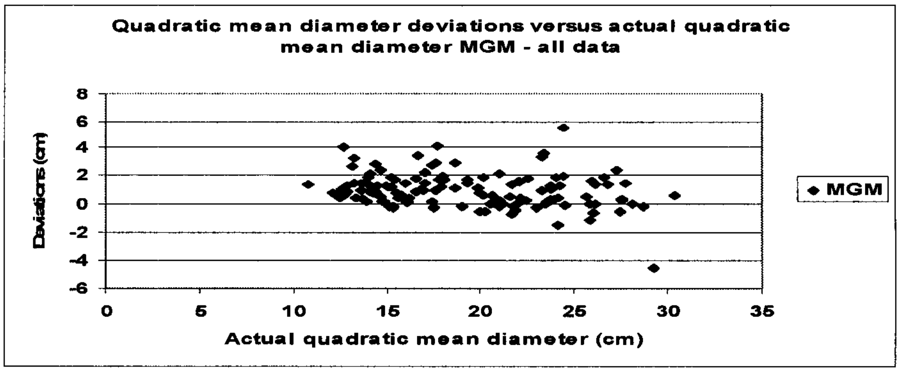


Appendix I.6 MGM total volume deviations (m^3) against actual total volume (m^3), basal area deviations (m^2) against actual basal area (m^2), density deviations (N/ha) against actual density (N/ha), and top height deviations (m) against actual top height (m) for all species combined.

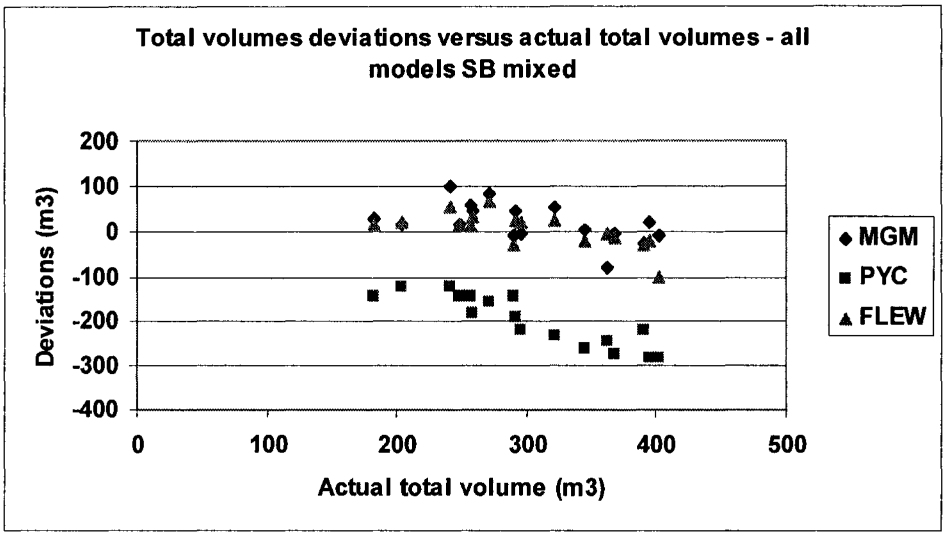


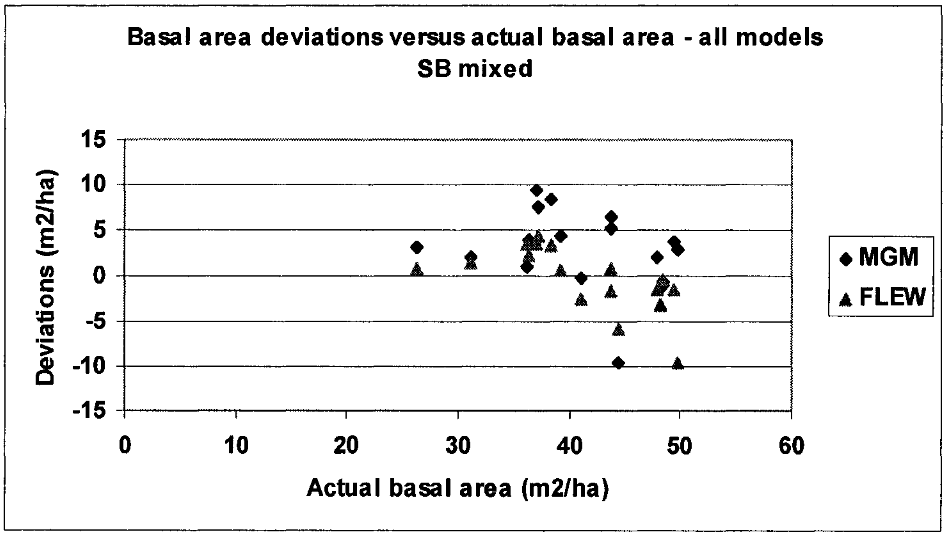


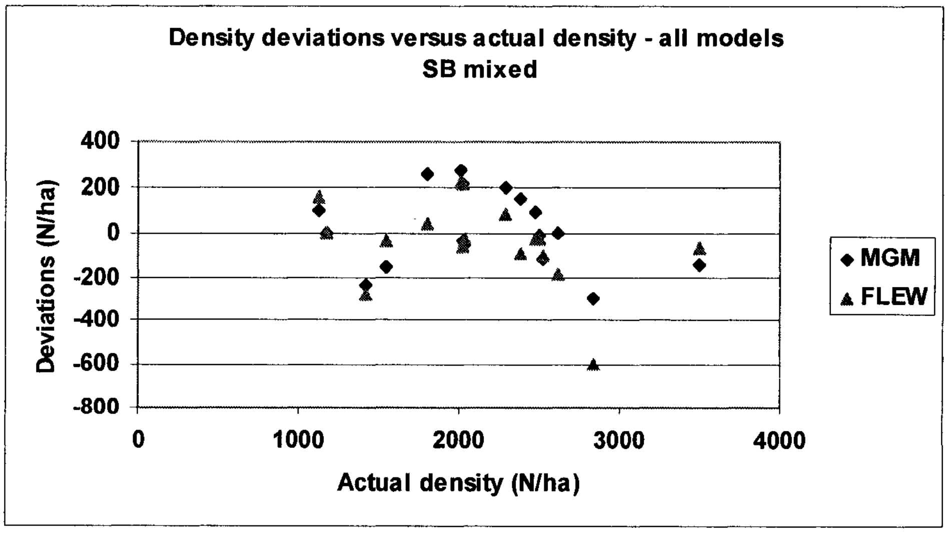


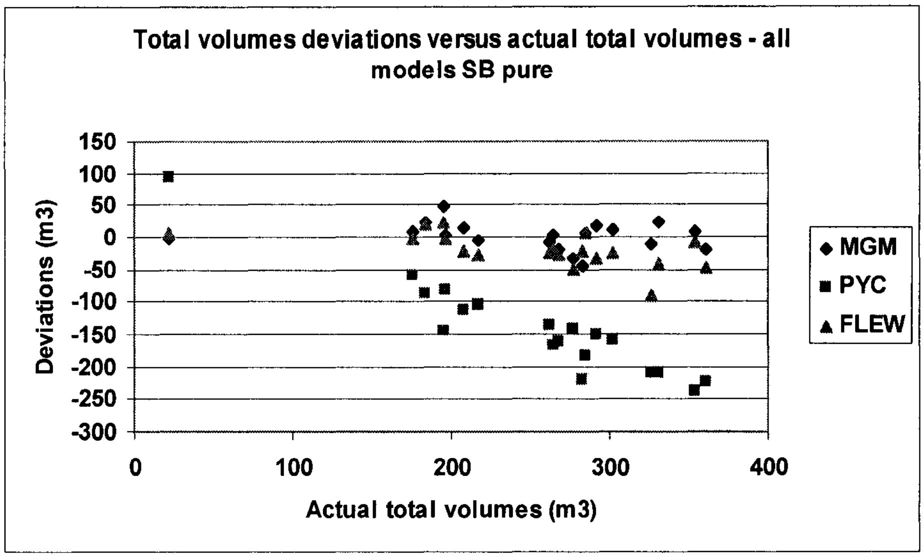


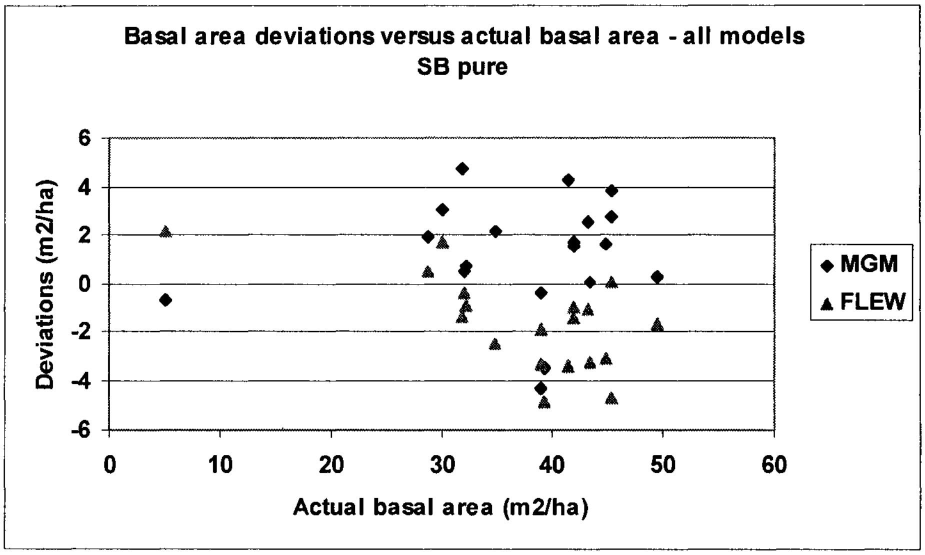
Appendix II. Deviations for total volume, basal area and density against actual values for total volume, basal area, and density by species association for all three models combined.

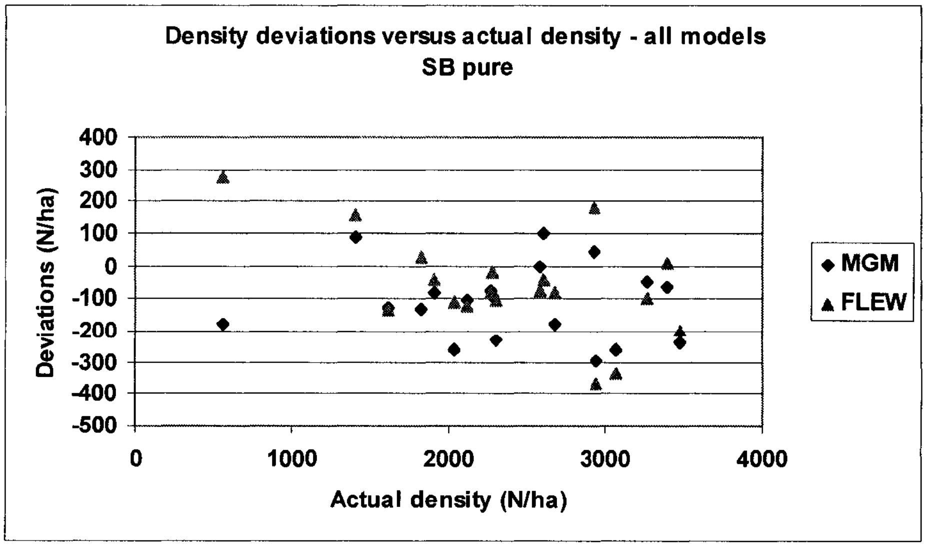

Total volumes deviations versus actual total volumes - all models SB mixed
Deviations (m3)
200
100
0
-100
-200
-300
-400
0
100
200
300
400
500
Actual total volume (m3)
MGM
PYC
FLEW

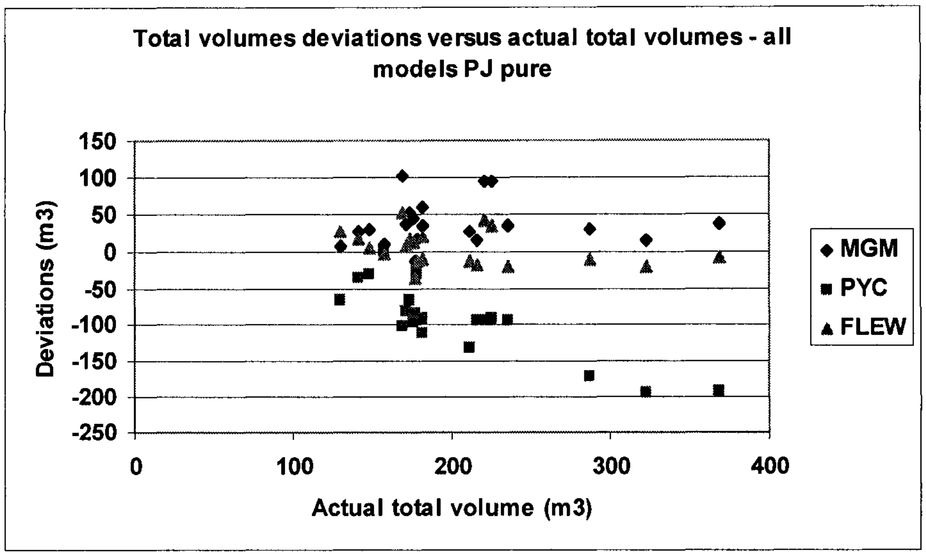

Basal area deviations versus actual basal area - all models SB mixed
Deviations (m2/ha)
15
10
5
0
-5
-10
-15
0
10
20
30
40
50
60
Actual basal area (m2/ha)
MGM
FLEW

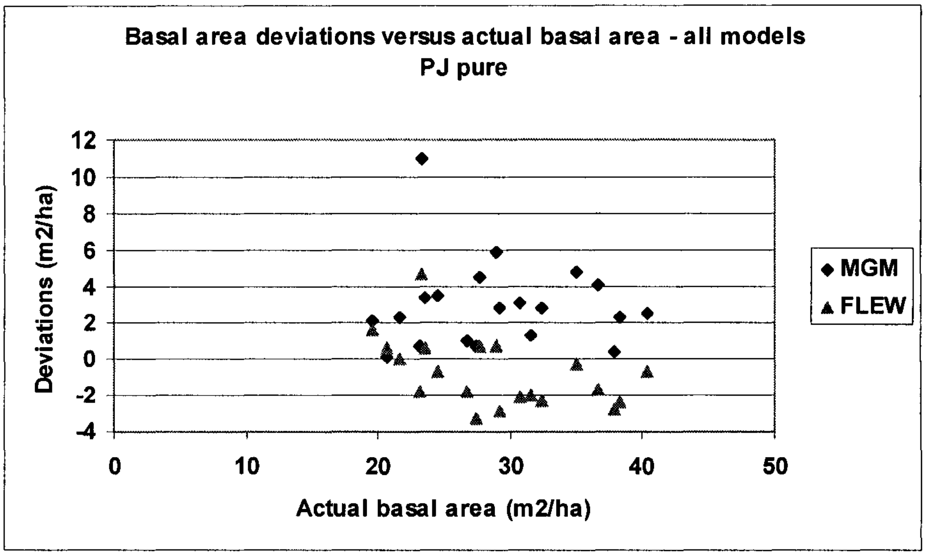

Density deviations versus actual density - all models SB mixed
Deviations (N/ha)
400
200
0
-200
-400
-600
-800
0
1000
2000
3000
4000
Actual density (N/ha)
MGM
FLEW

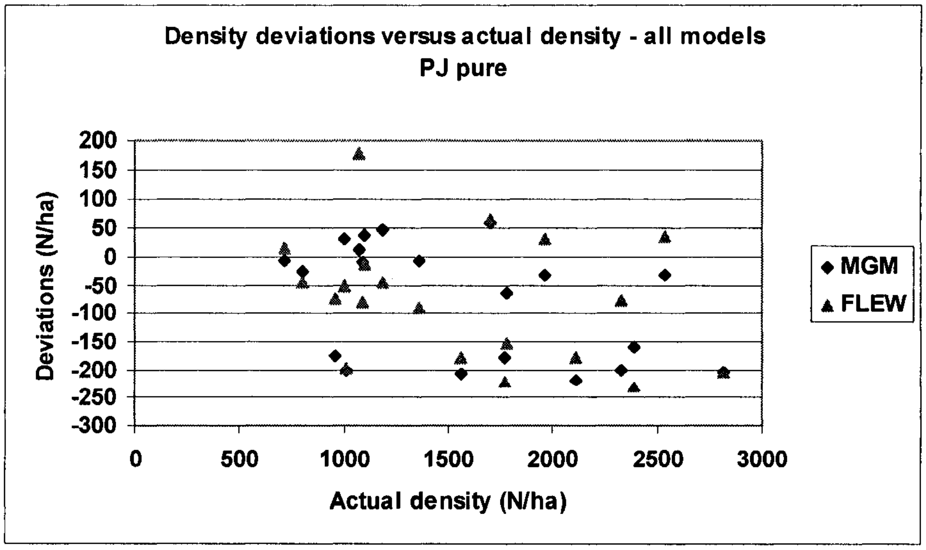

Total volumes deviations versus actual total volumes - all models SB pure
Deviations (m3)
150
100
50
0
-50
-100
-150
-200
-250
-300
0
100
200
300
400
Actual total volumes (m3)
MGM
PYC
FLEW

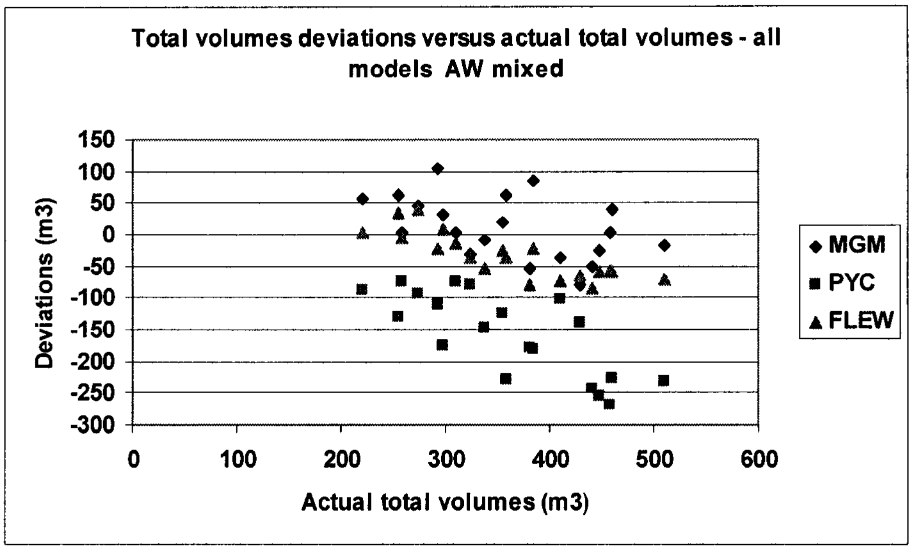

Basal area deviations versus actual basal area - all models SB pure
Deviations (m2/ha)
6
4
2
0
-2
-4
-6
0
10
20
30
40
50
60
Actual basal area (m2/ha)
MGM
FLEW


Density deviations versus actual density - all models SB pure
Deviations (N/ha)
400
300
200
100
0
-100
-200
-300
-400
-500
0
1000
2000
3000
4000
Actual density (N/ha)
MGM
FLEW

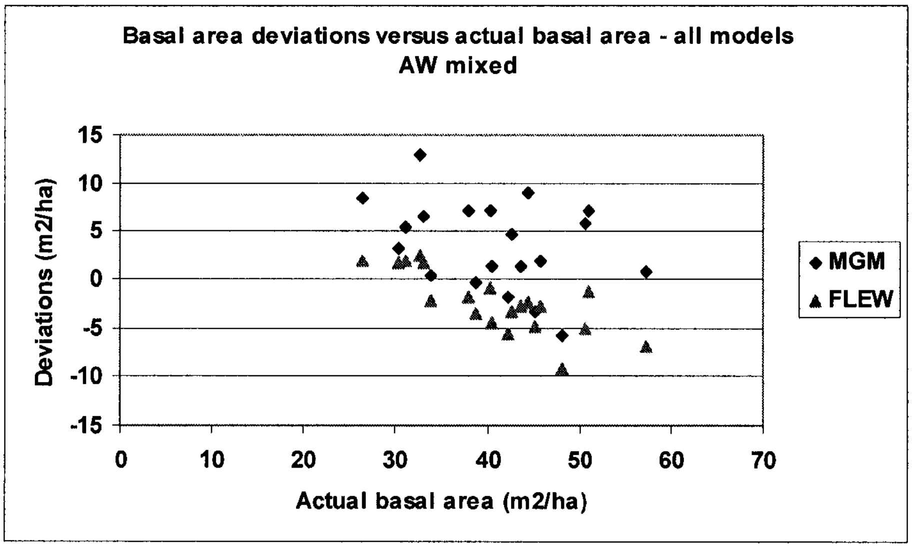

Total volumes deviations versus actual total volumes - all models PJ pure
Deviations (m3)
150
100
50
0
-50
-100
-150
-200
-250
0
100
200
300
400
Actual total volume (m3)
MGM
PYC
FLEW


Basal area deviations versus actual basal area - all models PJ pure
Deviations (m2/ha)
12
10
8
6
4
2
0
-2
-4
0
10
20
30
40
50
Actual basal area (m2/ha)
MGM
FLEW

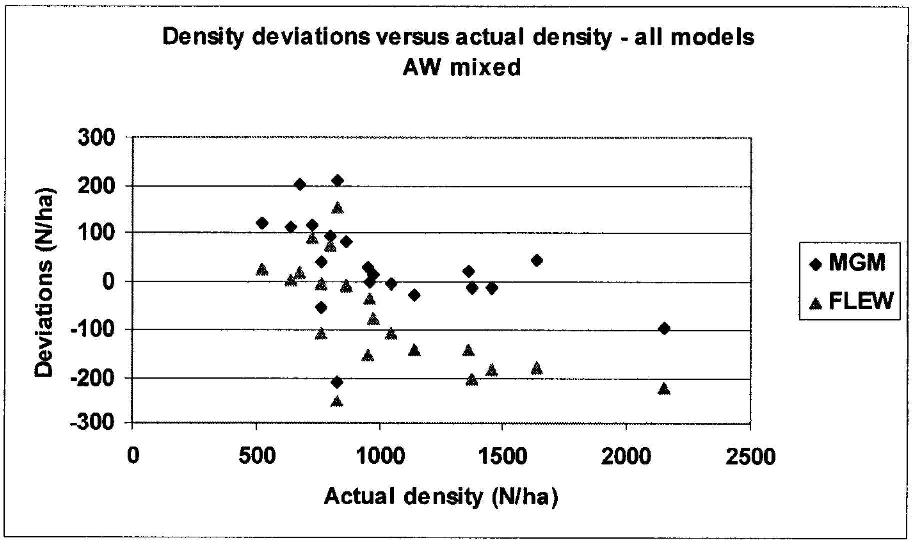

Density deviations versus actual density - all models PJ pure
Deviations (N/ha)
200
150
100
50
0
-50
-100
-150
-200
-250
-300
0
500
1000
1500
2000
2500
3000
Actual density (N/ha)
MGM
FLEW



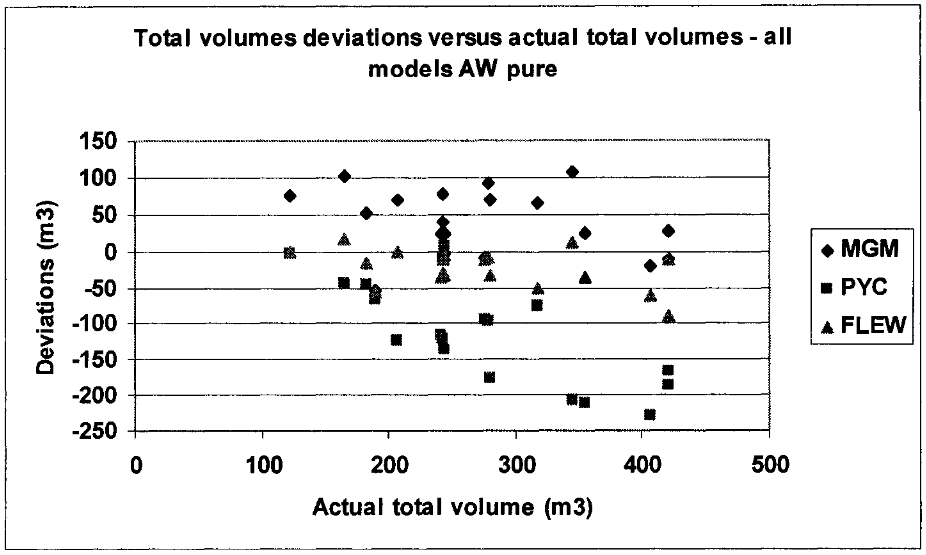
Total volumes deviations versus actual total volumes - all models AW mixed
Deviations (m3)
Actual total volumes (m3)
MGM
PYC
FLEW

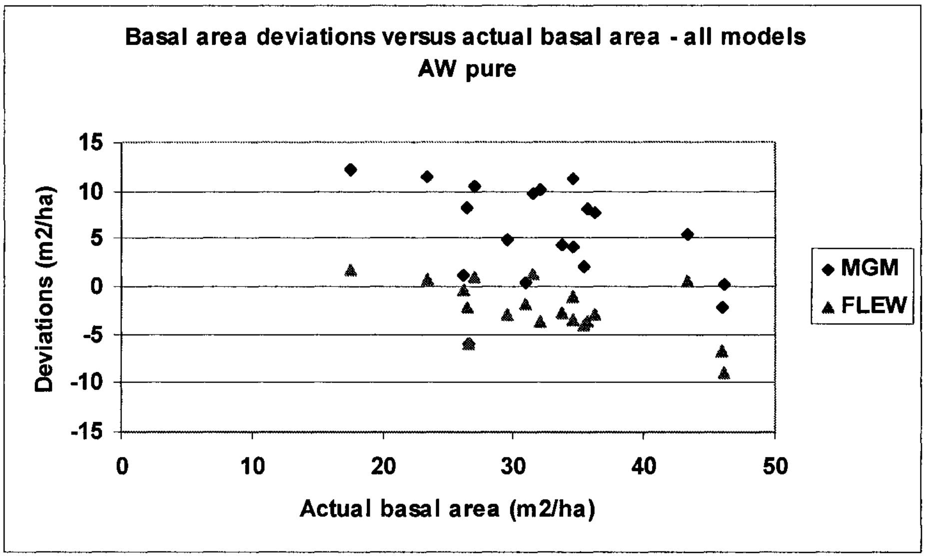


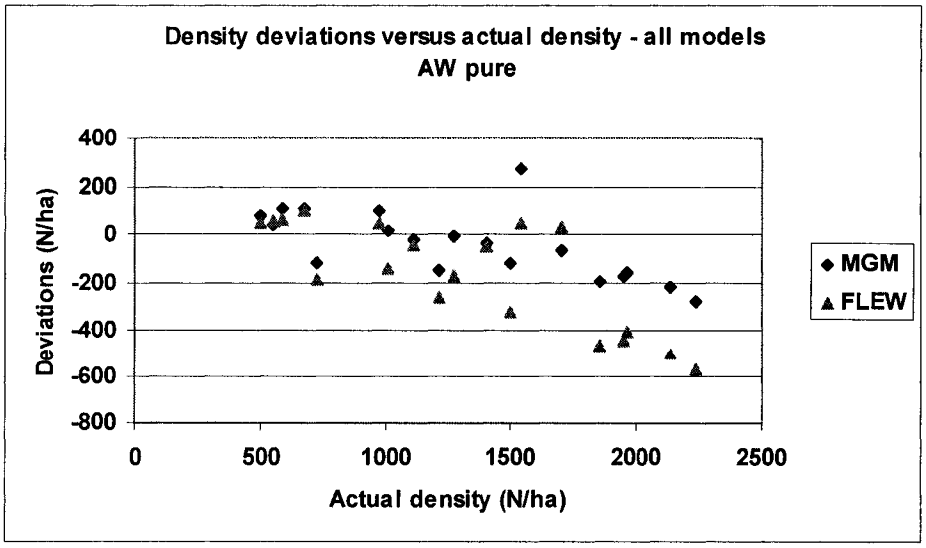
Basal area deviations versus actual basal area - all models AW mixed
Deviations (m2/ha)
Actual basal area (m2/ha)
MGM
FLEW

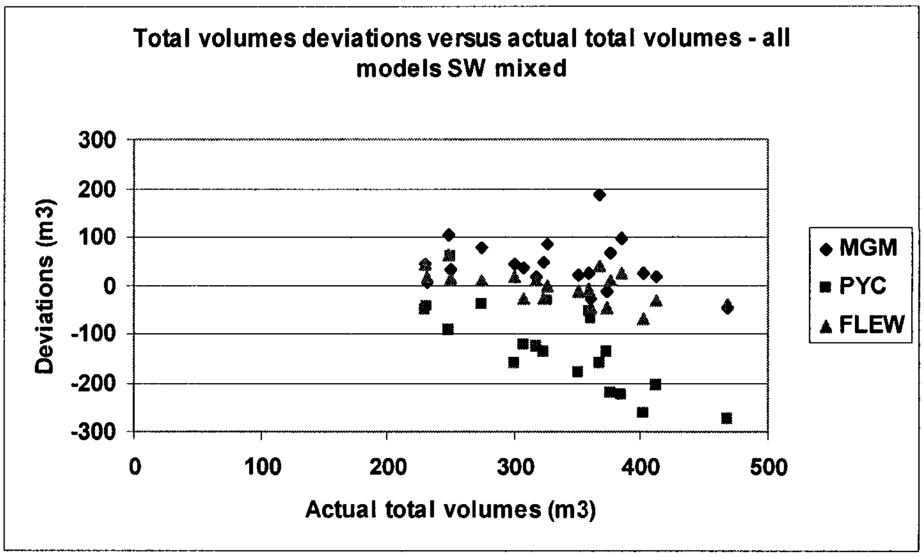


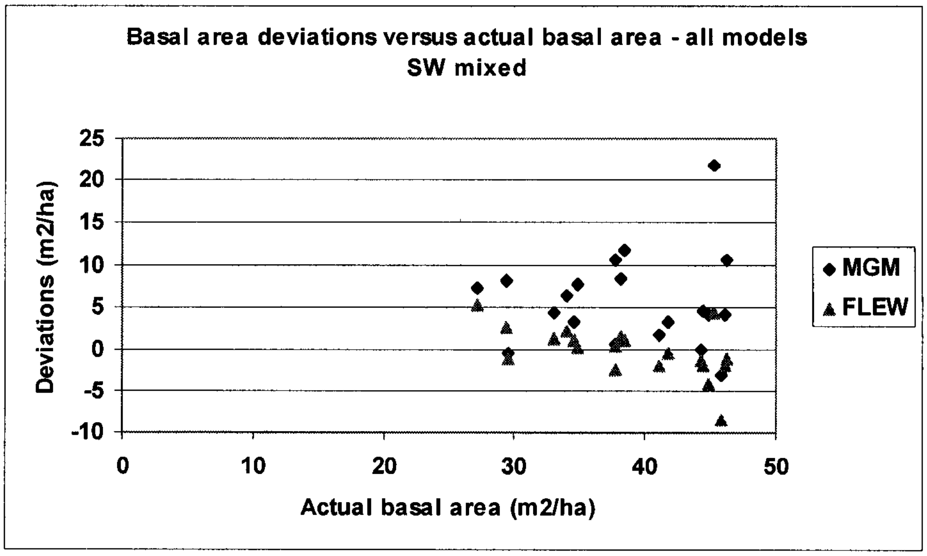
Density deviations versus actual density - all models AW mixed
Deviations (N/ha)
Actual density (N/ha)
MGM
FLEW

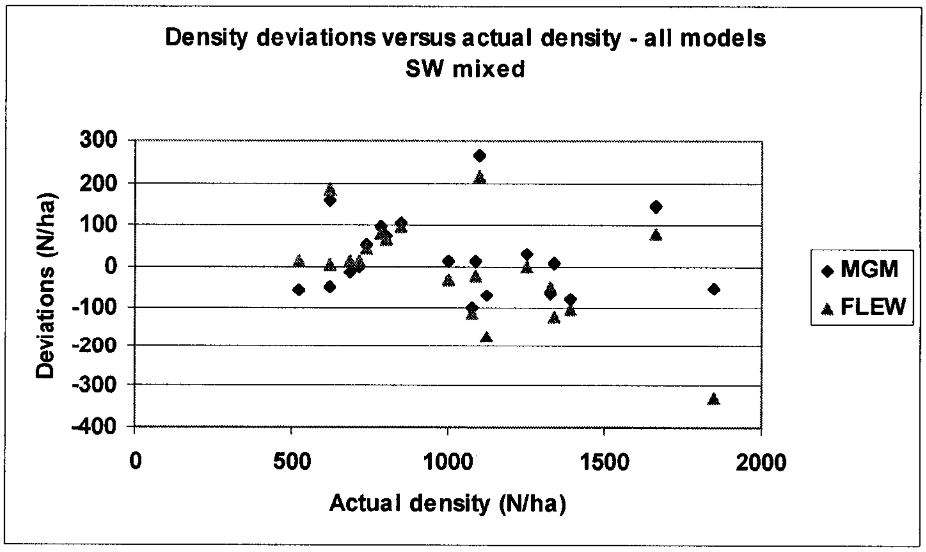

Total volumes deviations versus actual total volumes - all models AW pure
Deviations (m3)
Actual total volume (m3)
MGM
PYC
FLEW

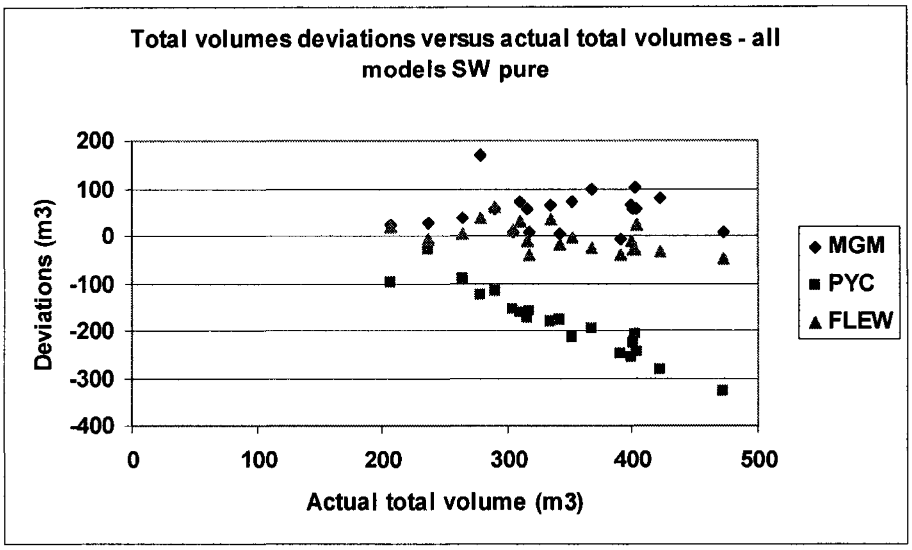

Basal area deviations versus actual basal area - all models AW pure
Deviations (m2/ha)
Actual basal area (m2/ha)
MGM
FLEW


Density deviations versus actual density - all models AW pure
Deviations (N/ha)
Actual density (N/ha)
MGM
FLEW

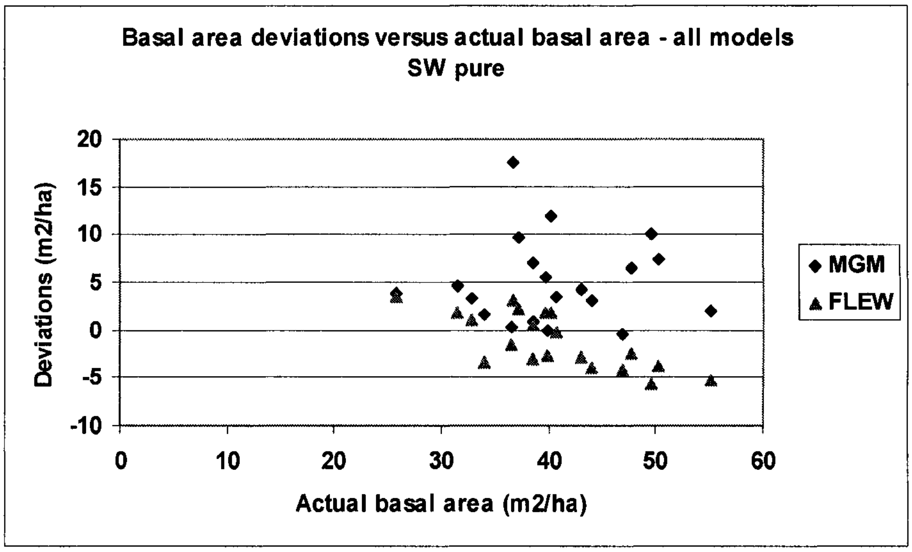

Total volumes deviations versus actual total volumes - all models SW mixed
300
200
100
0
-100
-200
-300
Deviations (m3)
0
100
200
300
400
500
Actual total volumes (m3)
MGM
PYC
FLEW


Basal area deviations versus actual basal area - all models SW mixed
25
20
15
10
5
0
-5
-10
Deviations (m2/ha)
0
10
20
30
40
50
Actual basal area (m2/ha)
MGM
FLEW

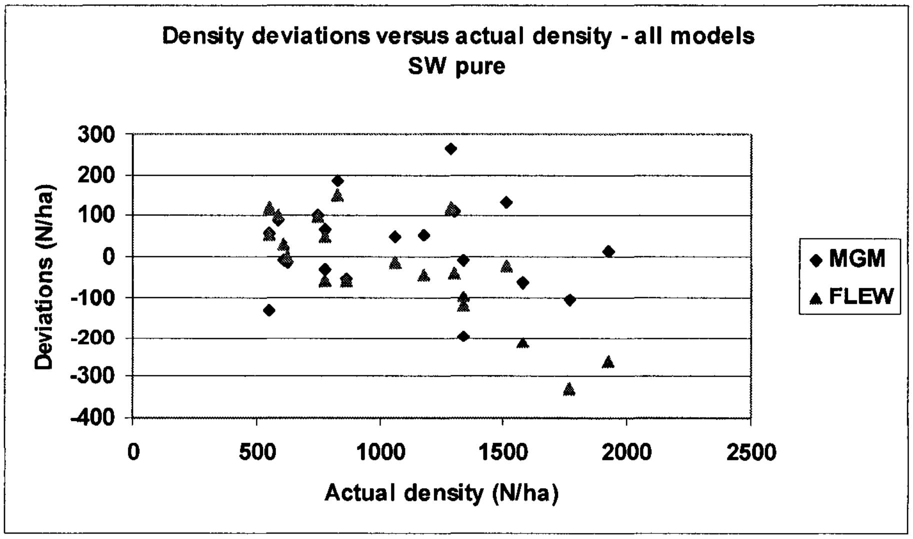

Density deviations versus actual density - all models SW mixed
300
200
100
0
-100
-200
-300
-400
Deviations (N/ha)
0
500
1000
1500
2000
Actual density (N/ha)
MGM
FLEW



Total volumes deviations versus actual total volumes - all models SW pure
Deviations (m3)
200
100
0
-100
-200
-300
-400
0
100
200
300
400
500
Actual total volume (m3)
MGM
PYC
FLEW



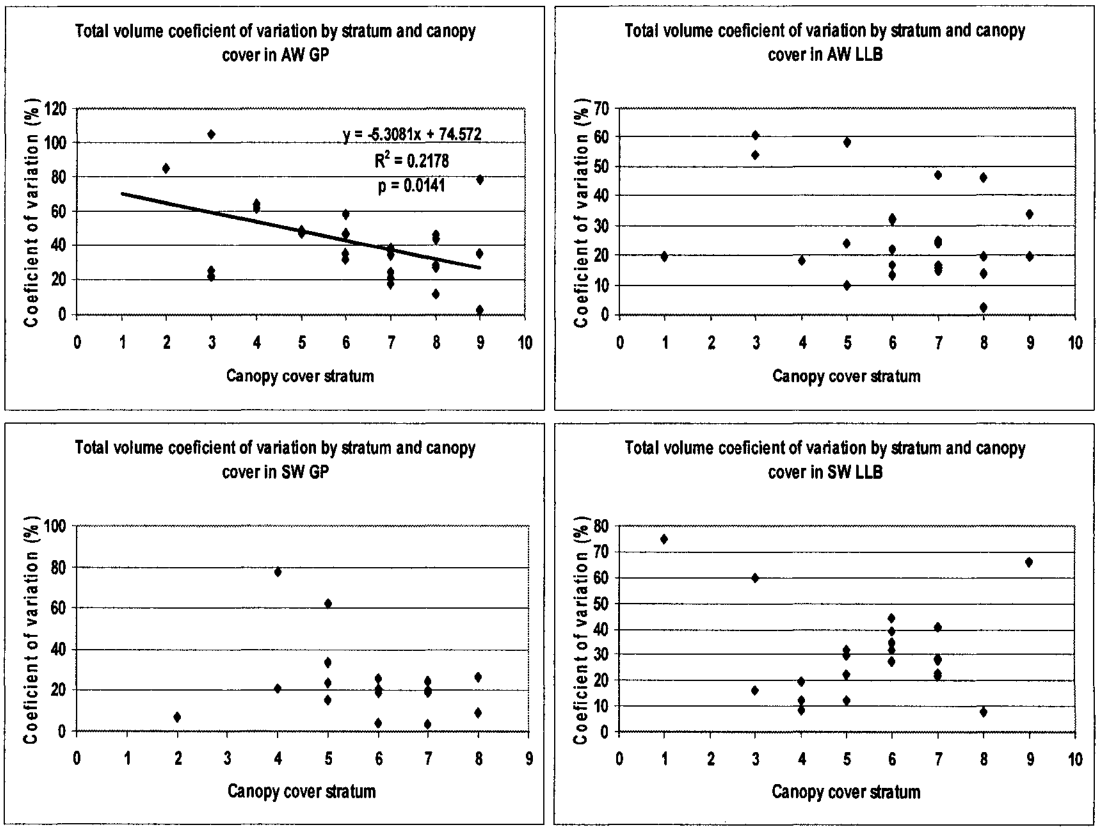
Basal area deviations versus actual basal area - all models SW pure
Deviations (m2/ha)
20
15
10
5
0
-5
-10
0
10
20
30
40
50
60
Actual basal area (m2/ha)
MGM
FLEW



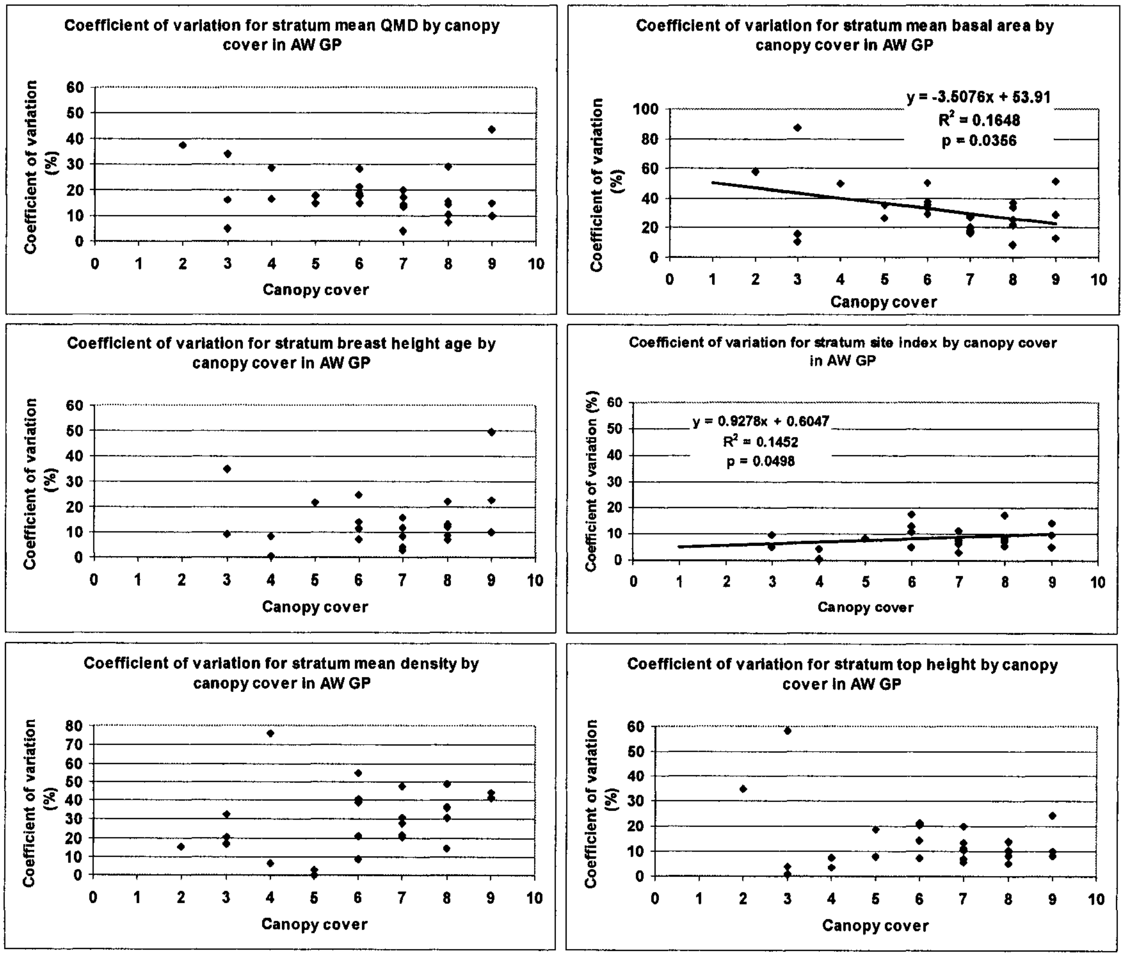
Density deviations versus actual density - all models SW pure
Deviations (N/ha)
300
200
100
0
-100
-200
-300
-400
0
500
1000
1500
2000
2500
Actual density (N/ha)
MGM
FLEW

Appendix III. Scatter plots showing the relationship between stratum coefficient of variation and canopy cover for all characteristics and four populations

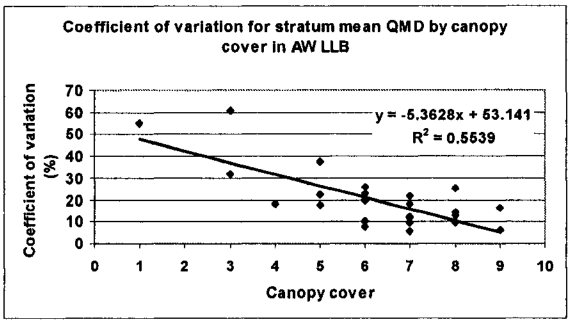
Appendix III.1 Scatter plots showing the relationship between total volume stratum coefficient of variation and canopy cover in the four populations

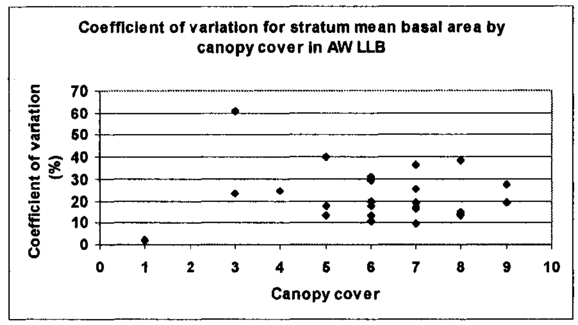


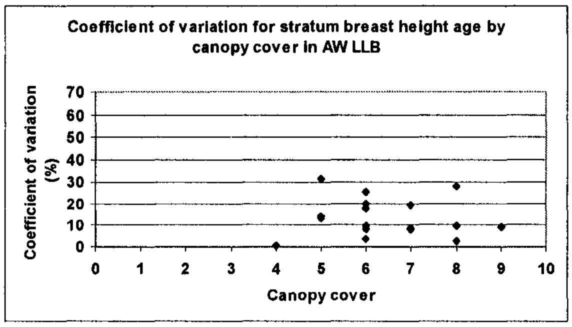
Appendix III.2 Scatter plots showing the relationship between stratum coefficient of variation and canopy cover for QMD, BA, breast height age, SI, density, and top height for pure aspen polygons in Grande Prairie

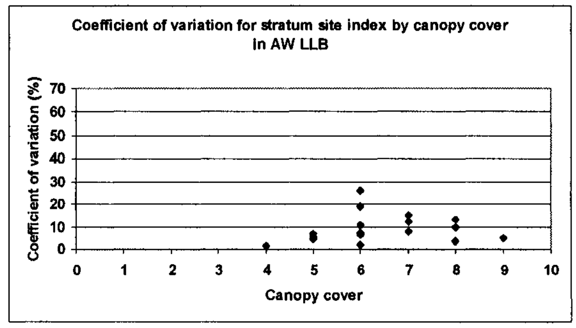


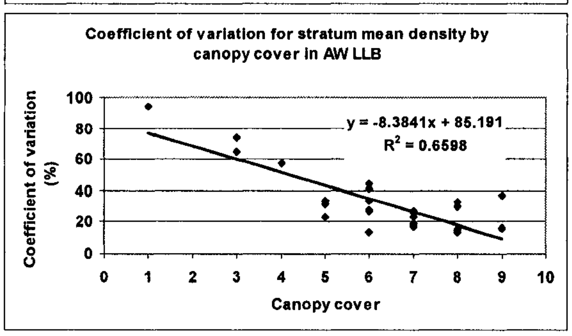
Appendix III.3 Scatter plots showing the relationship between stratum coefficient of variation and canopy cover for QMD, BA, breast height age, SI, density, and top height, for pure aspen polygons in Lac La Biche

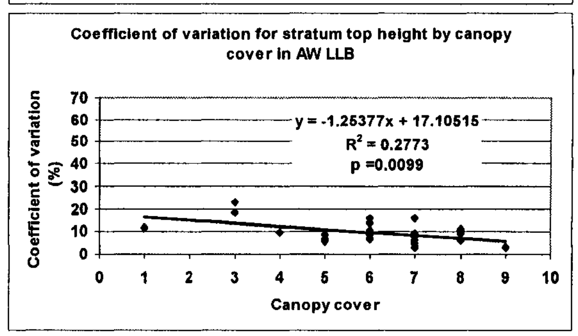




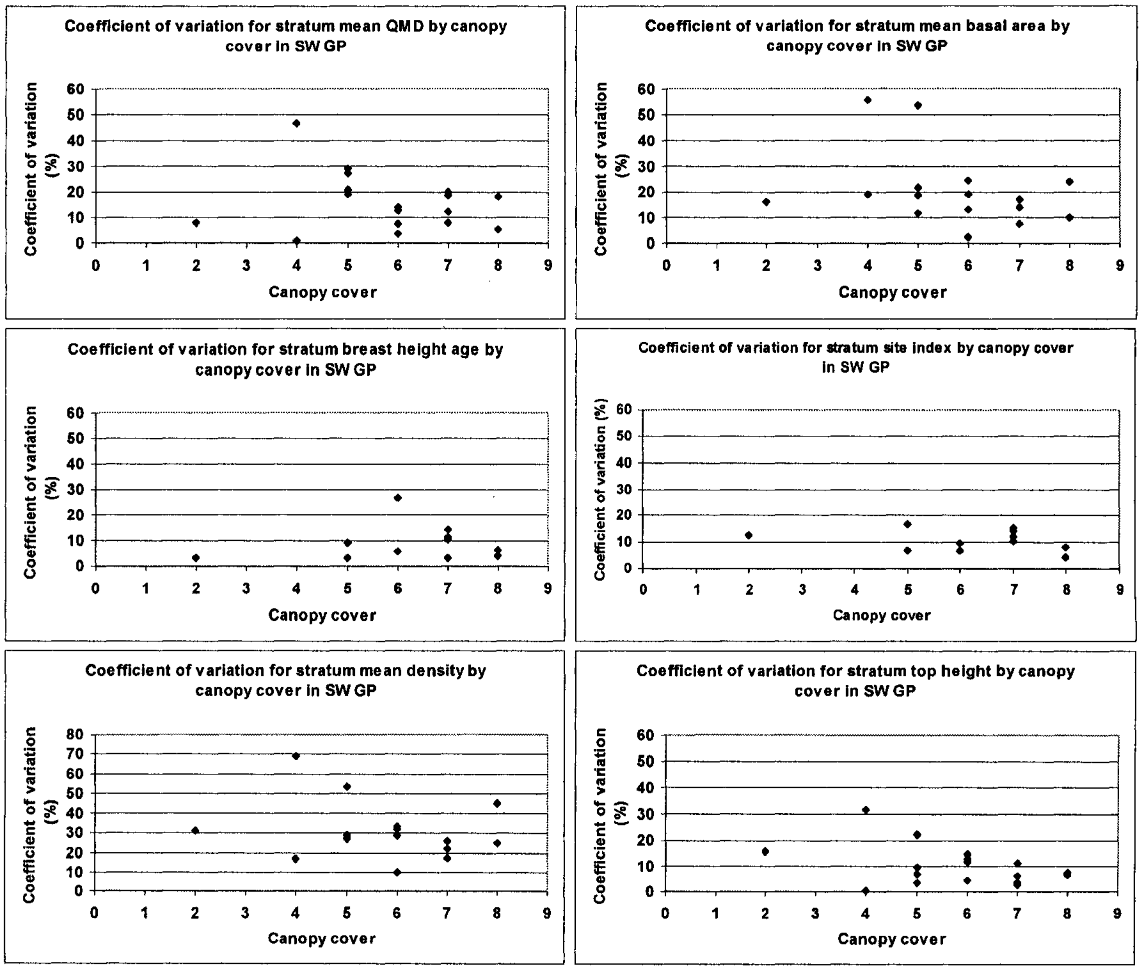








Appendix III.4 Scatter plots showing the relationship between stratum coefficient of variation and canopy cover for QMD, BA, breast height age, SI, density, and top height, for spruce dominated polygons in Grande Prairie



Appendix III.5 Scatter plots showing the relationship between stratum coefficient of variation and canopy cover for QMD, BA, breast height age, SI, density, and top height, for spruce dominated polygons in Lac La Biche