Possible Approaches for Relating Growth and Yield Models to Aerial Information

PART I – Literature Review and Data Sources

Prepared by: Temesgen Hailemariam, Ph.D., RPF and V. LeMay, Ph.D., RPF

University of British Columbia

Dept. of Forest Resources Management

2045-2424 Main Mall

Vancouver, BC V6T 1Z4

Submitted to: Mr. Barry Snowdon, RPF

BC Ministry of Forests

Forest Practices Branch

Victoria, BC, V8W 9C2

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1.0. Introduction

Forest inventories and analyses are conducted to support and guide forest management decisions to meet changing and increasingly complex forest management objectives. Management planning and interventions have historically been based on stand-level attributes such as volume and basal area per hectare. However, increasing demand on the forests and changes in societal values require resource managers to assess alternative management practices and their effects on stand structure. Forest inventory (using ground and air cruising) and growth and yield (GY) modeling play important roles in assessing these alternatives.

The province of British Columbia (BC) manages 59 million ha (145.8 million acres) of forestland similar in area to the entire national forests of the US (77.3 million ha, 191 million acres). This forestland is divided into various strata (polygons) based on forest cover types for forest inventory purposes. Each of these polygons has aerial stand attributes such as, species composition/mix (in %), crown closure (%), height class, age class, site class/site index, elevation, BEC zone/subzone, volume/ha (either photo interpreted or estimated using a yield prediction model), and stocking class.

The province of BC has also developed several growth and yield models for use in various regions of the province. Among these models, Prognosis^{BC} (adapted from the northern Idaho variant) is used in the Southeastern part of the province, while mixed-wood growth model (MGM) is used in Northeast part of the province. However, the estimates from these models have not been linked to aerial stand attributes or to the existing inventory database, and they have not been used to update polygon level estimates.

A tree-list is a tree-by-tree record of the tree species, diameter measures at breast height (dbh; measured at 1.3 m above ground), height, and expansion factor (to obtain stems per ha), while a diameter distribution indicates the frequencies of trees within defined diameter intervals (Clutter et al. 1983). Knowledge of the tree-list or the diameter distribution within a stand is useful in planning and designing new processing facilities, in supplying and operating existing processing facilities, in assessing stand structure and in assessing biodiversity at stand level. Expressing existing stand conditions using a tree list is also useful for landscape level analysis and planning purposes. Many GY models and simulators require some form of tree list to set initial conditions for the stand being modeled or projected. In such growth models, the use of an existing (actual) tree list to define an initial stand condition provides reasonable growth and yield estimates and future stand conditions. However, in many situations, individual tree measurement data from which a tree list may be constructed are not available. Hence, the ability to generate a reasonable tree list from a minimal amount of information or from an existing information source such as aerial stand attributes or forest cover labels is invaluable.

This report reviews and synthesizes approaches that are used to generate tree lists from aerial information and lists possible data sources for BC. The challenges in relating in relating GY models to aerial information and inventory databases are also discussed. The final report will include this report, summary of the tree list generation workshop (held on January 21, 2000), and results from pilot analysis project.

2.0. Approaches to Relate Growth and Yield Models to Aerial Information

Many approaches have been used to generate a tree list directly or indirectly. These approaches can be categorized into diameter distribution modeling and imputation methods.

2.1. Diameter Distribution Modelling

This method involves two steps in relating GY models to aerial stand information. First, a probability distribution function (PDF) is selected to describe a diameter distribution for each tree species. Parameters of the selected PDF are estimated from ground sample data. Reynolds *et al*. (1988) compared a variety of techniques for selecting, comparing, and validating diameter distribution models. The authors developed an error index to assess accuracy of diameter distribution models.

Second, the predicted parameters are regressed against aerial stand attributes using least squares (LS), non-linear least squares (NLS), weighted least squares (WLS), and seemingly unrelated regression (SUR) fitting methods. Based on how parameters are estimated, the diameter distribution modeling approach can be categorized into parameter prediction, percentile prediction, and parameter recovery methods. Once diameter distributions are estimated, the height and number of trees per hectare for each diameter class are predicted using various functions. These steps enable generation of tree list from aerial stand attributes.

2.1.1. Parameter Prediction

In this approach, parameters are estimated directly for the PDF using the ground data. Estimated parameters are regressed against stand-level attributes using an appropriate fitting procedure (Hyink 1980, Frazier 1981). The parameters of future diameter distribution are estimated from stand-level attributes.

A comprehensive listing and description of commonly applied PDFs is found in Johnson and Kotz (1970) and Lawless (1982). The Weibull distribution is the most widely used PDF to generate tree list from stand-level attributes. The parameters of the Weibull PDF are directly related to the location and shape, including skewed distributions (Bailey and Dell 1973). The GYPSY model (Growth and Yield Projection System) uses a Wiebull PDF to generate tree lists from stand age, stand height (top height or site height) and density (stems/ha of trees) (Shongming Huang, Alberta Lands and Forest Service, Pers. Comm.).

Biging *et al*. (1994) randomly generated individual tree dbhs from stand summary statistics such as basal area and number of trees per hectare by taking the inverse of the Weibull and negative exponential cumulative distribution function. Individual tree height and height-to-the base of crowns were estimated using predictive equations. Biging *et al*. used the negative exponential distribution function to characterize the diameter distribution of balanced, uneven-aged stands, as suggested by Meyers (1952). However, the stand summary attributes used in their study are not easily obtainable from aerial photos or satellite images.

The parameter prediction method is inefficient when there is weak relationship between the estimated parameters and stand-level attributes, and when inappropriate fitting techniques are employed (Bailey and Dell 1973). Smalley and Bailey (1974) and Feducci et al. (1979) found poor relationships between the Weibull parameters and stand-level attributes. These poor relationships can be ascribed to peakedness of the parameters and/or inefficient fitting techniques.

2.1.2. Percentile Prediction

Bailey *et al*. (1981) and Clutter et al. (1983) discussed the percentile prediction method as alternative to ML technique in estimating parameters of a given PDF. This method uses distribution percentiles to solve for the parameters of a given PDF (Bailey *et al*. 1981). For example, if three sample percentiles are known, each can be equated to its corresponding Weibull cumulative density function, and the three equations can be solved iteratively for estimates of the three Weibull parameters.

Dubey (1967) and Bailey *et al*. (1981) suggested that the 24th, 63rd, and 93rd percentiles provided the most efficient estimators of the Weibull parameters. These percentiles were converted to Weibull parameter estimates through the following three equations:

$$P_{24} = a + [-LN(0.76)]^{(1/c)}$$

$$P_{63} = a + [-LN(0.37)]^{(1/c)} = a + b$$

$$P_{93} = a + [-LN(0.07)]^{(1/c)}$$

Where: P_p is the diameter at which "p" percent of the trees in the stand are smaller; a, b, c are Weibull parameters; and LN= natural logarithm.

The solution to this system is initiated by numerically solving for "c" in the following expression:

$$\frac{(P63 - P24)}{(P93 - P63)} = \frac{[1 - 0.2744368^{(1/c)}]}{[2.65926^{(1/c)} - 1]}$$

Parameters a and b are then obtained through substitution.

2.1.3. Parameter Recovery

This method solves for parameters of a PDF from stand-level attributes and allows consistent mathematical relationship between stand and tree level attributes. The parameters of the PDF are recovered (predicted indirectly) by matching the moments of the PDF to predicted stand attributes (Vanclay 1994). Reynold *et al*. (1988) found that the parameter recovery approach had lower error index (gave better results) than the parameter prediction method for the Weibull PDF. However, the parametric recovery approach can have intractable computational difficulties with other PDFs such as Johnson's SB (Vanclay 1994).

Rustagi (1978) used a parameter recovery method to predict stand structure from average and maximum stand diameter. A similar approach could be used to recover parameters from stand aerial attributes. Hyink (1980) used the parameter recovery method to avoid problems associated with the parameter prediction method.

Reynolds *et al*. (1998) found that the error index in parameter recovery and parameter prediction methods decreased, as the size of individual plots increases. The error index dropped off rapidly, as the number of plots increased up to 25 plots.

2.1.4. Others

The B-spline based probability density estimation technique was studied to generate a diameter distribution, instead of assessing a known distribution (Gehringer and Redner 1992, and Redner and Gehringer 1994). Stands were classified using stand attributes such as age, site index, dominant species, quadratic mean diameter, treatment history, and then a probability density estimate of the diameters in each class was computed. The density estimates for intermediate stand values were interpolated. This approach is very similar to the parameter recovery methods that are used classically. Silverman (1986) and Thompson and Tapia (1990) provide detailed discussions on other estimation and simulation methods.

2.2. Imputation Methods

Imputation is "replacing missing or non-sampled measurements for any unit in the population with measurements from another unit with similar characteristics" (Ek *et al* 1997, Van Deusen 1997). Imputation can be used for modeling (Rubin 1987), forest inventory (Holm *et al*. 1979) and regeneration prediction (Ek *et al*. 1997). However, the use of imputation in GY modelling is not well explored (Ek *et al*. 1997). Imputation is unbiased only if the underlying sample is also unbiased. Otherwise, imputation methods will provide biased results.

A tree list can be determined directly from a database using imputation methods, instead of through modeling a distribution (Silverman 1986). Unlike the diameter modeling approach, imputation methods:

1) can maintain both spatial and attribute data when interpolating tree lists (Moeur and Stage 1995). This can be ascribed to the similar variance-covariance matrix of the population and the samples (Ek *et al*. 1977);

2) do not place restrictions on the form or shape of the underlying distribution. The advantages of no restrictions are important in using any form of data and in simplifying the assumptions needed by parametric distributions; and

3) are totally data-based. As new data are collected or become available, they may be added to a database and then used. This is not the case with the classical parameter recovery approach where when new data are obtained a completely new analysis must be performed.

Maltamo and Kangas (1998) pointed out that imputation, unlike other estimation methods, requires large databases for predicting diameter distributions of reference stands. Imputation methods in forest resource analysis include nearest neighbor method, most similar neighbor method, k-nearest neighbor, geo-statistical estimation, and tabular imputation models.

2.2.1. Nearest Neighbor Method (NN)

Moeur (1999) used a nearest neighbor imputation method by picking a reference stand based on the Euclidean distance computed on an auxiliary variable. In NN method, a selected reference stand is one that has the lowest Euclidean distance from the auxiliary variables space. This approach assumes the observed tree list of the nearest neighbor stand will represent the tree list of a target stand.

2.2.2. Most Similar Neighbor Method (MSN)

Unlike the NN method, MSN considers the relationships between auxiliary and inventory variables in selecting a reference stand. Thus, the NN method can be characterized as univariate imputation method while the MSN method can be characterized as multivariate imputation method. Moeur and Stage (1995) used MSN by selecting the most similar neighbor stand based on Euclidean distance on the auxiliary variables (e.g., digital terrain data, aerial photography, and satellite imagery), weighted by correlation coefficients between the auxiliary and inventory variables. Weighting the Euclidean distance by canonical correlation coefficients improved the imputation results obtained by Moeur and Stage (1995). The MSN approach assumes that the observed tree list of the most similar neighbor stand will represent the tree list of the target stand.

Moeur and Hershey (1998) compared three types of MSN: 1) non-spatial MSN; 2) quasi-spatial MSN where only geographic coordinates (X and Y) were added as additional variables; and 3) fully spatial where geographic coordinates and a variogram estimator were included. The most similar neighbor was selected using satellite signature (e.g., TM bands), and species and basal area per hectare were imputed. Even though the inclusion of spatial information did not alter the imputation results substantially, Moeur and Hershey (1998) argued that the interpolation of tree list and map for un-sampled polygons will be realistic and reliable when both spatial and attribute data are maintained.

MSN can be used to substitute non-response VRI samples. Non-response VRI samples occur when no data is available due to (1) denied access on private land, (2) access route problems, (3) dangerous wide game dens (Penner 1999). However, MSN may not replace non-response samples on steep and dangerous slopes, as such stands will not be part of the reference stands in selecting the most similar neighbor.

In her sampling simulation study, Moeur (1999) found that at least 20% of stands must be sampled to obtain reasonable imputation results. In MSN, the most similar neighbor was selected based on weighted Euclidean distance function of the inventory and auxiliary variables (Moeur and Stage 1995). Similar stands can be selected using distance functions such as Euclidean (Moeur and Stage 1995), Mahalanobis, and absolute difference (Maltamo and Kangas 1998).

Euclidean distance (d_{xy}) for two sets of variables $X^{|}= [x_1, x_2, \ldots, x_n]$ and $Y^{|} = [y_1, y_2, \ldots, y_n]$ is given by:

$$d_{xy} = \sqrt{\sum_{i}^{n} (x_i - y_i)^2}$$

Maltamo and Kangas (1998) found that the absolute difference distance function, as the most efficient distance function to detect similarity between attributes of the reference stand (*i*) and target stand (*j*). The absolute difference distance function can be given as (after Maltamo and Kangas 1998):

$$d_{ij} = \sum_{l=1}^{p} c_l \mid (x_{il} - x_{jl}) \mid$$

Where: x_1 is the stand characteristics, l is 1, …, p, and c_l is the coefficient for stand variable x_1.

The Mahalanobis distance function, D^2, has not yet been explored in selecting the most similar neighbor stand or the k-neighbor stands for imputing tree lists. D^2 between two groups of observations is given by:

$$D^2 = (\bar{X}_1 - \bar{X}_2)' S^{-1} (\bar{X}_1 - \bar{X}_2)$$

Where:

$$S = \frac{n_1 S_1 + n_2 S_2}{n_1 + n_2}$$

Where: X_1 and X_2 are the mean vectors of the two groups; S is weighted average of the variance-covariance matrices of the two groups, S_1 and S_2; and n_1 and n_2 are the sample sizes in the two groups.

2.2.3. K-nearest Neighbor (k-nn)

In this method, the tree list for the target stand is obtained as weighted averages of tree lists of the k-neighboring stands. Contrarily, for MSN (Moeur and Stage 1995), the tree list of a target stand is obtained only from the selected most similar neighbor stand. Thus, weighting of tree lists is not required.

Maltamo and Kangas (1998) compared three approaches to k-nn for predicting the tree list of a target stand. The three approaches varied how the diameter distributions of the reference stands were obtained. The diameter distributions studied were: 1) smoothed with Weibull function; 2) smoothed with the Kernel method; and 3) empirical distributions. The authors found that the use of empirical distributions resulted in the most accurate prediction of diameter distributions in their study. Even though the authors focused on diameter distribution, their results indicate that tree list for a target stand can be imputed from tree lists of the k-neighbor stands.

Maltamo and Kangas (1998) pointed out that in a large-scale inventory, the search for the k-nearest neighbors can be time-consuming and the unbiasedness of the k-nn estimates could not be guaranteed. Maltamo and Kangas (1998) identified three steps to carry out the k-nn method. These were setting 1) a distance function to select the most similar reference stands, 2) the number of nearest neighbors to be used, and 3) a weight function for weighting the reference stands.

2.2.4. Tabular Imputation Model

Ek *et al*. (1997) developed “tabular imputation models” to estimate post-harvest forest stand characteristics. These models were developed from inventory plot data that were set into tables by forest cover types. The predictions from the tabular imputation models were used, as input of regeneration to STEMS growth model and were projected into the future. This approach can also be used to relate GY models to aerial attributes by setting tables of tree lists that are indexed by sets of aerial stand attributes.

2.2.5. Geostatistical Estimation (GS) for species distribution

Unlike MSN methods, GS techniques account for the spatial distribution of tree species, without considering their relationship with other tree species and with other tree layers. This method considers the spatial structure in a sample data and estimates the distribution of tree species across a landscape.

Moeur and Hershey (1998) used a two-step GS process to interpolate species distribution maps to un-sample stands. First, species occurrence was estimated using Boolean (for absence or presence of a species) or Kriging indicators. Second, species percent basal area per acre was estimated using Gaussian simulations. However, the reliability of this method depends on the accuracy of the reference forest cover maps.

3.0. Data Sources for Relating Growth and Yield Models to Aerial Information

Data sources that can be used to relate GY models and aerial stand attributes can be categorized into ground data and remotely sensed data. An ideal data source for linking GY models to aerial stand variables should represent forest conditions under consideration and should include:

1. the input variables for the selected GY model and stand aerial variables. These variables need to be consistent and compatible with each other;
2. stand history and stand structure to analyze past and future conditions;
3. a wide range of age and tree size including small trees so that stands of different age and tree size classes can be considered; and
4. site characteristics such as slope, aspect, elevation, BEC zone and subzones.

3.1. Ground Data

In BC, there are four major sources of ground data for most GY modeling and inventory initiatives. These data sources include Permanent Sample Plots (PSPs), Vegetation Resources Inventory Plots (VRIs), Timber Appraisal Plots (Cruise plots), and Audit Plots. Ground data sources vary in their layouts, variables included, and population represented (Table 1). A brief summary of the advantages and disadvantages of each ground data source to link GY models to aerial stand attributes is described below.

3.1.1. Permanent Sample Plots (PSPs)

PSPs are generally large, providing a reasonable amount of data to develop a diameter distribution model in each polygon, and to employ various imputation techniques. PSPs represent homogenous stands (i.e., no internal variability) with normal stocking conditions. Since PSPs are purposively selected within a polygon, they generally are biased measures of the polygon. Thus, linking GY models to aerial stand attributes using an unrepresentative stand/forest conditions could lead to biased results.

3.1.2. Cruise Data

Cruise data are collected from mature stands that are ready to harvest and are identified in a cutting permit. These data sets are systematically selected from a concentrated geographic location and could cover one or more polygons. Cruise data sets do not represent a wide range of stand conditions, age and tree size classes. Thus, the use of these data to link GY models to aerial stand attributes is limited.

3.1.3. Vegetation Resources Inventory (VRI) Plots

The VRI is intended to obtain unbiased estimates for large units of area by laying out ground samples across the province. An ordered systematic (OS) sampling design has been used to select sample polygons with probability proportional to polygon size (PPS). Since the OS sampling design lacks unbiased estimate of standard error of the mean, stratified probability proportional to size with replacement (PPSWR) sampling design has been proposed for possible future use (Ott 1999).

Table 1. Summary of ground data sources in BC.

Data Source	Layout/ Type of Plot	Plot size	Variables included	Target population/ Area represented	Number of sample
PSPs	Selective FAP[1]	Large FAP	Timber & other attributes including site analysis data	Province of BC Spread through out the province Not well distributed spatially May not represent under stocked & mixed wood stands Homogeneous forest condition & no internal variability	Few PSPs over the province
VRI	Grid VRP[2]/FAP	One main plot & 4 satellite plots Small Limited # of sample trees	Timber & other attributes including site analysis data	Province of BC Forest-district by forest-district basis	Not many areas have VRI plots
Appraisal/ Cruise	Systematically selected VRP/FAP	Small to medium Multiple plots per polygon	Timber	Based on cutting permit May not represent under stocked & mixed wood stands Lacks small tree sample. Very concentrated Targeted at specific stand types Could be in over-lapping polygons	Systematically selected & very concentrated Most is one plot/ha
Audit	Grid VRP/FAP	Small to medium Four full measure and five count plots in a polygon for mature stands in a grid Nine full measure plots in a polygon for immature stands	Timber	Management Unit Concentrated & clustered in a management unit Program is being phased out	Many plots for the area covered

[1]FAP = Fixed Area Plot; 2 VRP = Variable Radius Plot

VRI plots will not serve well to link GY models to aerial stand attributes for the following reasons:

1. VRI plots may not be representative of a polygon, as the VRI plots are intended for larger areas than polygons;
2. the number of sample trees in a VRI plot may be few, resulting in a poor estimated diameter distribution model for the polygon;
3. VRIs are intended for large areas whereby sampled polygons and plots are far apart. Thus, VRI plots would not allow testing or employing some of the imputation techniques used to link GY models to aerial information (e.g., spatial approaches); and
4. currently there is a limited number of VRI plots and these do not cover the province.

3.1.4. Audit Data

The audit data sets are representative samples of a management unit (i.e., a TSA or TFL). In audit sampling, stands are identified into two classes.

1) Mature stands include stands older than 60 years of age. In a TSA or most TFLs, 50 polygons are selected with probability proportional to polygon size (PPS) for species composition, volume, and age sampling. In each sampled polygon, grids are laid out and four full measure and five count plots are sampled at a randomly selected grid point.

2) Immature stands include stands younger than 61 years but greater than free growing status. In a TSA or most TFLs, 20 polygons are selected with PPS to assess site index, species composition, and volume in age class 3 stands (41 to 60 years of age). In each sampled polygon, nine fixed area or variable radius plots (in a cluster) are sampled at a randomly selected grid point (Min. of Forests 1998).

The audit data set is suggested as a potential source to link GY models to stand aerial attributes for the following reasons:

1. the audit data sets cover a wide range of forest conditions, stand types, age, and tree size classes;

2. since the audit data sets are intended for a management unit, sampled polygons and plots are not as far apart with VRI. This would allow testing or employing some of the imputation techniques used to link GY models to aerial information (e.g., spatial approaches);
3. the audit data includes new inventory labels such as number of trees per hectare and crown closure at a unit interval (class);
4. future data collection initiatives (e.g., continuous forest inventory plots) can be used as or augment audit data to link GY models to aerial stand attributes; and
5. currently there is large number of audit data representing wide range of management units in BC.

3.1.5. Large Scale Photos (LSP)

LSPs have a scale larger than 1:12,000 (Lillesand and Kiefer 1979). Therefore, individual tree attributes such as height and crown diameter can be measured directly, as with ground plots. LSPs can replace ground plots to obtain tree list in remote locations and in areas where access costs are high. Penner (1999) suggested the use of LSPs instead of ground sampling for steep, dangerous, and non-vegetated VRI plots. However, this type of data are not currently available in BC. With advances in digital camera technology, LSPs can become potential sources of data to link GY models to aerial stand attributes.

3.1.6. Other Sources of Data

Other ground sources include the Intensive Forestry Program Installations (IFP), Silviculturally Treated plots (ST), NIVMA TRENDS, EXPLORE, and PROBE. However, these data sources are not suitable for linking GY model estimates to aerial stand attributes, as they do not represent the population of natural or managed stands (J.S. Thrower & Assoc. Ltd. 1999).

3.2. Remotely Sensed Data (RSD)

Forest types have been mapped using RSD data such as air photos, satellite images, and scanned information. RSDs could contain both temporal and spatial attributes of a forest stand (species composition, crown closure, stocking class, height class, age class) and site conditions including elevation and biogeoclimatic (BEC) zone. Thus, they can used to link GY models to aerial stand attributes.

3.2.1. Aerial Photographs

Black and white photos (1:15,000) have been used to classify various types of forests, develop forest cover maps, delineate polygons, and extract aerial stand attributes. Bonner and Morrier (1981) used aerial photographs to classify mixed wood forests into 5-metre site index classes with a 76% success rate.

3.2.2. Satellite Images

Satellite images (i.e., Landsat TM spectral reflectances and transformations) provide both temporal and spatial information about stand and site conditions. Moeur (1998) used Landsat TM satellite imagery in MSN interpolations. The images consisted of raw spectral band of 30m by 30m pixels and vegetation index transformations. Satellite images have been used to classify forestland productivity (Fox et al. 1985), estimate growth index (Vanclay and Preston 1990) and assess pest and disease surveys. However, their use to obtain tree list have not been thoroughly explored or reported.

3.2.3. Airborne/ Laser Scanners

Airborne scanners are used to measure canopy height profiles (Means et al. 1999) and canopy surface area (Lefsky et al. 1997). Means et al. (1999) outlined how canopy profiles are measured by stating that scanner sends laser pulses toward the ground and measures the return time for reflections off vegetation surfaces and the ground. The reflected laser pulses are used to estimate mean canopy height and canopy reflections.

Means et al. (1999) regressed canopy heights against stand basal area and above ground biomass. Canopy height profiles are used to describe the vertical structure of forests. They may also be used to obtain tree lists indirectly (i.e., by using functional relationships between crown heights and dbh), although this has not yet been researched.

4.0. Challenges to Relate Growth and Yield Models to Aerial Information

The following problems are anticipated in generating tree list from aerial stand attributes and in linking of ground data to aerial stand attributes.

4.1. Data Paucity and Suitability

Insufficient or concentrated ground data for some types of stands and for some species within a stand would not allow testing the performance of the diameter distribution and imputation approaches to relate GY models and aerial stand attributes. This can be ascribed to limited sample size and geographical distribution.

Ek (1990) emphasized that plot size is less important than the limit for small tree size, as these trees are potential in-growth trees that can affect the accuracy of future projections. This is due to the different growth and mortality equations used for small and large trees in GY models. Plot sizes are important to obtain reasonable number of trees to develop good diameter distribution model for the polygons and to cover wide range of tree size classes.

A selected data set needs to include small trees and a wide range of age classes so that forest stands of different size and age classes are considered. Some data sets in BC do not include small trees and young or regenerating stands (e.g., the cruise data sets). The use of such data to link GY models to aerial stand attributes will be limited.

4.2. Weak Relationships

Weak relationships between aerial stand attributes and diameter distribution as well as with Weibull parameters are also reported by various studies (Smalley and Bailey 1974, Feducci 1979).

4.3. Interpolation and Species Assignment

Diameter distribution can be predicted easily. However, attaching species composition to the generated/estimated diameter will be a challenging task. Simulation studies are required to assess the order of species and dbh estimation. Gehringer et al. (1992) estimated dbh and later assigned species according to the proportion of species in the sample. The authors assumed that generated tree-list would have similar species composition and density as their respective parent population. Moeur and Hershey (1998) used kriging and simulation routines to estimate species occurrence.

Consistency between aerial stand estimates and estimates obtained using generated/imputed tree lists are required. Estimates need to be consistent and compatible for all variables including species composition, basal area, and volume. Consistency and compatibility are important when aerial stand attributes of non-sampled polygons fall outside the range of the sample polygons.

4.4. Aggregation and Weighting of Polygons

Aggregation of polygons and the weights given to each polygon affect the tree-list that can be obtained. This can ascribe to differences in the distribution of tree sizes, species, and density of trees among or between subject polygons. These differences will also be seen when tree lists are generated at stand-level or management unit level (i.e., a tree list for a TSA or a TFL).

4.5. Photo Interpretation

The accuracy of the remotely sensed data, including photo interpretation is crucial, in order to obtain accurate results. Aerial photos can be out-dated, resulting in inaccurate forest cover information, as stands change over time due to harvesting and other interventions**.** Photo interpretation on young, decayed, and in dense stands can be a problem, as these types of stand are difficult to accurately analyze them from aerial photographs.

5.0. Summary

Tree lists can be used as the starting condition to initiate a GY model and then to provide periodic feedback on stand GY estimates and to update inventory within reasonable margin of error. Thus, accurate prediction of forest conditions across landscapes can be obtained by linking GY models to aerial stand attributes.

An ideal method for generating tree list, besides being flexible, should have minimal estimation error, provide an accurate representation of the target stand, and include a wide range of tree size and age classes. Generating tree lists using the diameter distribution modelling approach is efficient when there is inadequate data set while the imputation methods are more flexible and when there are large data sets and spatial attributes are considered. An approach that combines these two approaches and also that considers the size of available data will provide sound and efficient projections.

The audit data sets cover a wide range of forest conditions, stand types, age and tree size classes. These data sets provide an opportunity to assess the performance of the diameter distribution modeling and the various approaches, and to link GY models to aerial stand attributes.

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