Vegetation Resources Inventory Statistical Adjustment for the Lignum IFPA Area

Prepared for

Tracy Earle, RPF
Inventory Forester
Lignum Ltd.
Williams Lake, BC

Project: LIG-013

March 31, 2002

J.S. Thrower & Associates Ltd. *Consulting Foresters*
Vancouver – Kamloops, B.C.

Executive Summary

Lignum Ltd. (Lignum) has implemented a Vegetation Resources Inventory (VRI) on their Innovative Forestry Practices Agreement (IFPA) area. The full VRI process includes five elements: photo-interpretation, ground sampling, tree decay study (net volume adjustment factor sampling), statistical adjustment, and within-polygon variation sampling.

In the statistical adjustment phase, adjustment relationships for different attributes are developed between the photo-interpretation estimates and the ground-sampling measurements. The end product is a statistically unbiased inventory database.

After adjustment, volume, height, age, site index, basal area, quadratic mean diameter, and number of tall fir trees were, on average, lower than the photo-interpretation estimates, while stems/ha was higher. The adjusted inventory database will provide Lignum with better information for managing their IFPA area.

Attribute	Initial Estimate	Adjusted Estimate	Difference (%)
Live whole-stem volume less top & stump, decay, waste, breakage			
4cm+ - All stands	141.1 m^3/ha	131.8 m^3/ha	-6.6
12.5cm+ - Pl leading stands	Unknown	80.3 m^3/ha	-
17.5cm+ - non-Pl leading stands	Unknown	105.4 m^3/ha	-
Lorey height	17.0 m	15.5 m	-8.8
Average breast-height age	104 yrs	101.1 yrs	-2.8
Site index	17.4 m	14.3 m	17.8
Basal area	22.5 m^2/ha	18.8 m^2/ha	-16.4
Stems/ha	846 tr/ha	1,201 tr/ha	42
Quadratic mean diameter	18.4 cm	14.1 cm	-23
Number of tall fir trees/ha	26 tr/ha	8 tr/ha	-69
Value ($/ha)	Unknown	$5,542/ha	-

These adjusted estimates were obtained using the Boston Bar protocol.

Acknowledgements

Several people contributed to the success of this project. We thank Kim Iles (Kim Iles & Associates Ltd.) for reviewing the adjustment procedures. Lawrence Wilson (Inland Timber, Williams Lake), and Bob Krahn and Alf Kivari (Ministry of Sustainable Resources Management, Terrestrial Information Branch) provided valuable information about the ground samples.

Table of Contents

List of Tables

List of Figures

1. INTRODUCTION

1.1 BACKGROUND

Forest Renewal BC and Lignum Ltd. (Lignum) signed a multi-year agreement to develop and promote innovative forestry in the Cariboo Forest Region as part of Lignum's Innovative Forestry Practices Agreement (IFPA). The purpose of the IFPA is to test innovative or new treatment regimes to improve forest productivity and enhance employment. One of the key components of the IFPA is the Vegetation Resources Inventory (VRI).

The full VRI process includes five elements: photo-interpretation (the Estimation Phase), ground sampling (the Ground Sampling Phase), tree decay study (net volume adjustment factor [NVAF] sampling), statistical adjustment (the Adjustment Phase), and within-polygon variation (WPV) sampling.[1]

1.2 PROJECT OBJECTIVES

The objectives of this project were to statistically adjust the Lignum IFPA VRI timber attributes using:

1. *the Ministry of Sustainable Resources Management (MSRM) standard adjustment procedure, and*
2. *the Boston Bar protocol.*

The MSRM and the Ministry of Forests (MOF) Timber Supply Branch require that the VRI database be adjusted using the MSRM standard adjustment procedure.[2] With this procedure, only height, age, and live net merchantable volume are adjusted. The Boston Bar protocol is an alternative adjustment procedure where all timber attributes (height, age, all live and dead volumes, species composition, basal area, stems/ha, and value/ha) are adjusted.[3] Lignum intended to demonstrate with this project that both adjustment procedures can be used for timber supply analysis with no marginal difference, and that the Boston Bar protocol provides unbiased estimates for more attributes than the MSRM standard adjustment procedure.

1.3 REPORT OBJECTIVES

The objectives of this report were to describe the analytical procedures used to adjust the VRI database, display the results, and discuss the implications for Lignum.

1.4 TERMS OF REFERENCE

J.S. Thrower & Associates Ltd. (JST) was contracted to carry out the statistical adjustment of Lignum's IFPA VRI database. Guillaume Thérien, *PhD,* prepared this report. Tracy Earle, *RPF* was Lignum's project leader.

[1] WPV sampling, not described in this report, is a process to find accurate estimates for individual stands, providing a measure of how well the final adjusted estimates match the individual polygon estimates.

[2] Ministry of Sustainable Resources Management. 2001. Vegetation Resources Inventory Attribute Adjustment Procedures. Draft Version 4.2, September 2001. 37 pp.

[3] J.S. Thrower & Associates Ltd. 1998. Vegetation Resources Inventory Statistical Adjustment–Final Report. Unpublished Report. Contract No. MFI-401-038. Vancouver, BC. 24 pp.

2. METHODS

2.1 STUDY AREA

Lignum's IFPA area is located in the Cariboo Forest Region and covers approximately 610,000 ha. The area is divided into three blocks near Alexis Creek, Williams Lake, and 100 Mile House (Figure 1). Only the Vegetated Treed (VT) polygons (545,971 ha) were considered in this adjustment project.

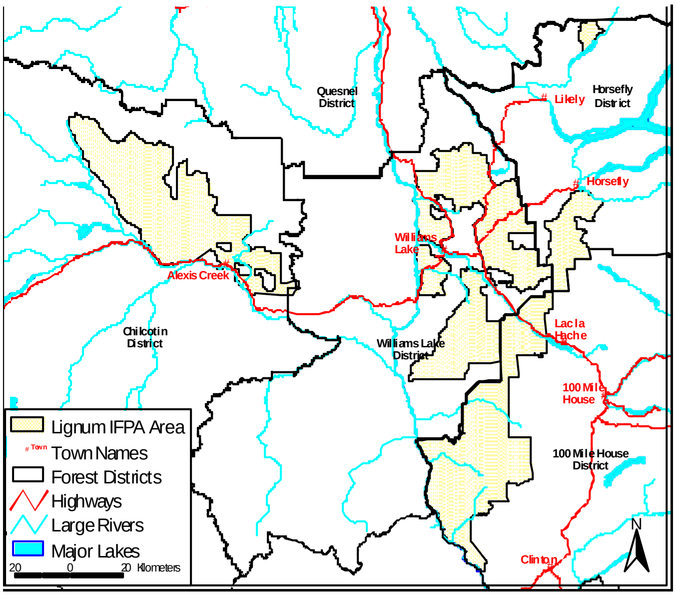


Figure 1. Map of Lignum IFPA area.

2.2 DATA

The Estimation Phase used photos taken in July 1998 and July 1999. Photo-interpretation occurred between December 1998 and June 2000 using the MSRM *VRI Photo-Estimation Procedures, version 2.2*, published March 31, 1999. The Estimation Phase included two attributes (volume and number of tall fir trees/ha) that are not standard VRI attributes. Lignum also provided a layer ranking in the fall of 2001.

In the Ground Sampling Phase, 372 plots were established throughout the IFPA area by Lignum (345 plots), the Williams Lake Forest District (16 plots), and the 100 Mile House Forest District (11 plots). Nineteen (19) plots were located in non-vegetated treed polygons for an actual sample size of 353 in the VT population. Each sample was weighted proportionally to the number of hectares it represented within the 100 Mile House or Williams Lake Timber Supply Areas (Table 1).

Table 1. Sample size and weight.

Timber Supply Area	Area (ha)	Sample Size	Relative Weight
100 Mile House	177,708	118	1.0000
Williams Lake	433,126	254	1.1323
Total	*610,834*	*372*	

Field sampling began in 1997, however most samples were taken in 1998. This difference was not accounted for in the adjustment process; all plots were assumed to have been sampled the same year.

Ground samples were established in the IFPA area before the new VRI polygon boundaries were delineated. Once the VRI polygons were delineated, all auxiliary plots were spatially located within these polygons. Those auxiliary plots that were not located in the same VRI polygon as the integrated plot centre (IPC) were deleted from the data compilation. JST compiled the ground volumes and dollar value/ha using a proprietary program.[4] The MSRM compiled all other attributes.

[4] As of March 2002, the MSRM was still evaluating volume compilation algorithms and did not want to release an algorithm before it was fully tested. The JST algorithm gives unbiased estimates of volumes and value that should be very close to the MSRM official estimates when these estimates are released.

2.3 ANALYSIS

The analysis followed two methods: the Boston Bar protocol (Figure 2) and the MSRM standard adjustment procedure (Figure 3) protocols. Different assumptions and output were required for each protocol.

In the Boston Bar protocol, all timber attributes with a corresponding ground measurement were adjusted. The estimated total attribute was first adjusted using the ratio of means method. That total was then distributed among polygons with the geometric mean regression (GMR) if the coefficient of determination (R^2) was greater than or equal to 25%[5], or with the ratio of means method when the relationship was weaker. Any individual polygons' adjusted estimates were multiplied again by a correction factor, if necessary, to ensure the sum of all adjusted polygon estimates matched the adjusted total.

In the MSRM standard adjustment procedure[6], height and age are first adjusted using a ratio of means method. An attribute-adjusted VDYP volume is then generated using the adjusted height and age. This attribute-adjusted volume estimate is then adjusted using a ratio of means method. No other attributes are adjusted.

2.4 EXAMPLE

To illustrate the adjustments, a polygon taken from the inventory database will be followed through each step in the processes (Figure 2 and Figure 3). The example polygon is 093A001-18 (Table 2).

Table 2. Example polygon attributes from polygon 093A001-18.

Attribute	Value	Attribute	Value
Species composition	$At_{60}Fd_{40}$	Leading Spp height	27 m
Volume	140 m^3/ha	Leading Spp age	130 yrs
Basal area	30 m^2/ha	Leading Spp site index	18 m
Stems/ha	275 trees/ha	Second Spp height	18 m
Tall fir trees/ha	0 trees/ha	Second Spp age	80 yrs
Quadratic mean diameter	37.3 cm	Second Spp site index	14.6 m
Average age	110 yrs	Lorey height	23.4 m

2.5 BOSTON BAR DATABASE PREPARATION

2.5.1 Estimation Phase Database

Problem 1. The Estimation Phase database needs to be obtained and augmented.

The Estimation Phase database was provided by the photo-interpretation contractor (Forest Dimensions Inc., Victoria, BC), who was working to MSRM specifications. The following modifications were made to the original database:

i) *Site index was estimated* for each polygon/layer combination using *SiteTools, version 3.2i*.

5 The 25% limit was arbitrarily chosen.
6 The MSRM standard adjustment procedure is often referred to as the Fraser protocol.

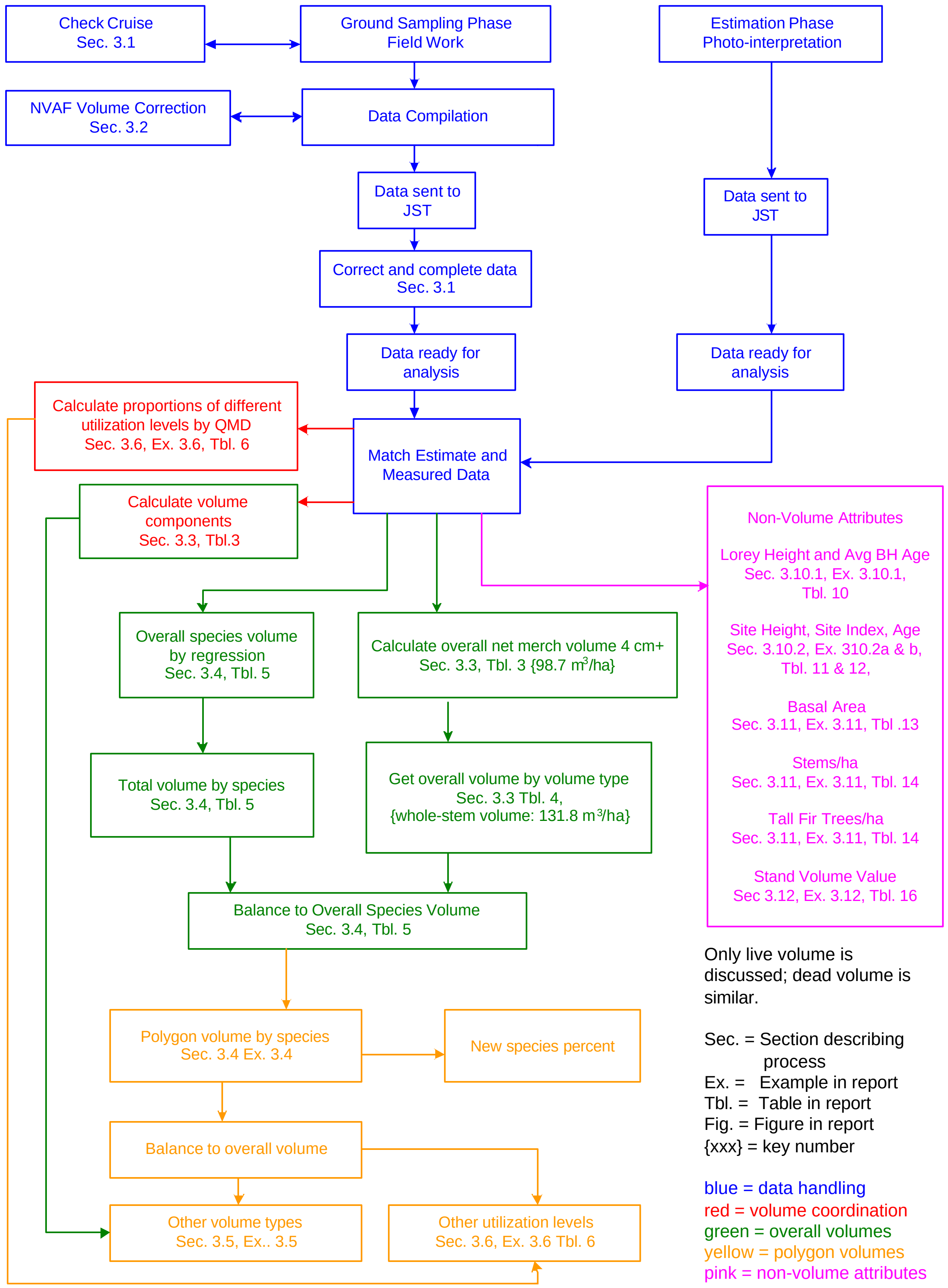


Figure 2. Boston Bar protocol flow-chart.

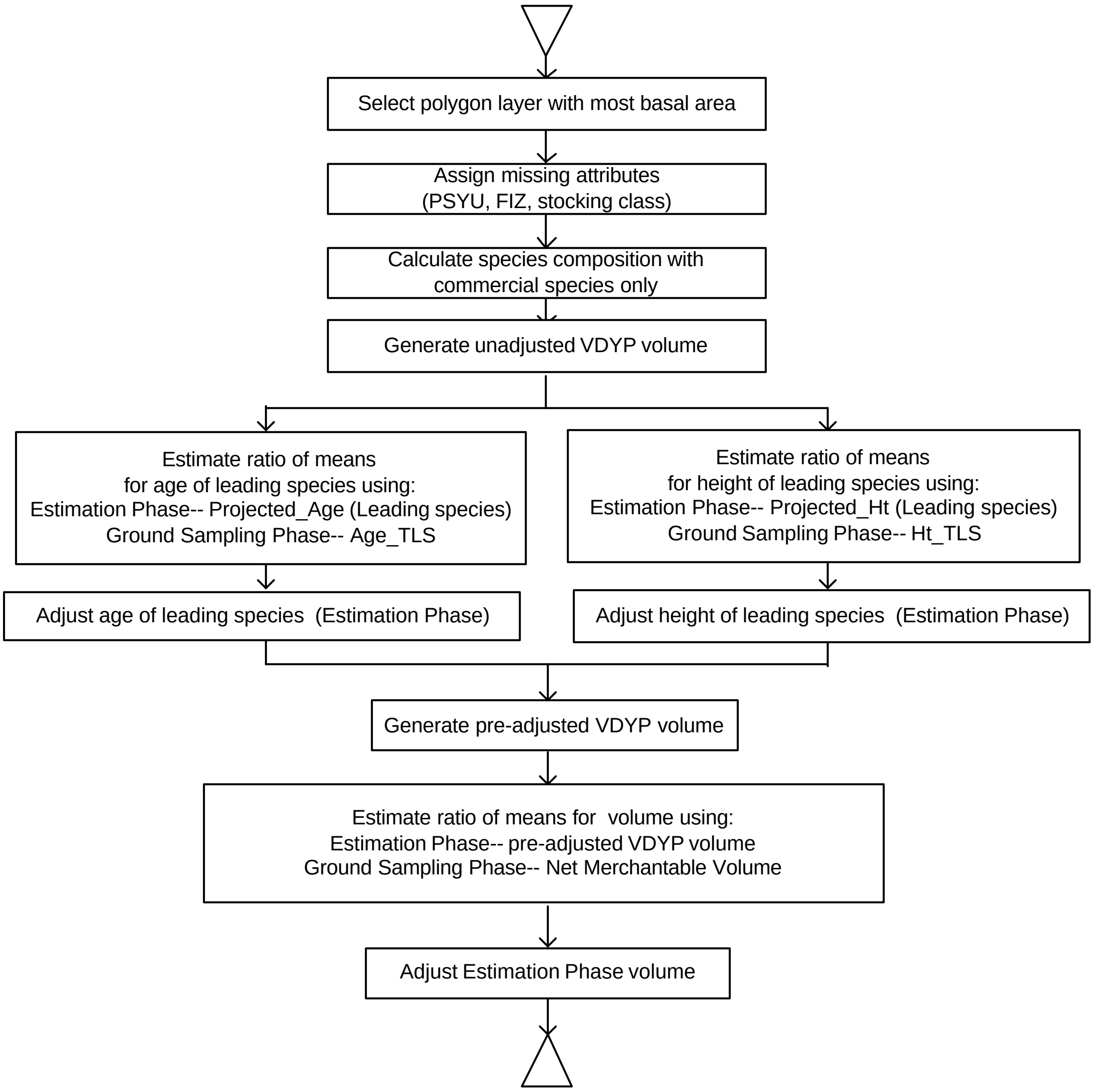


Figure 3. MSRM standard adjustment procedure flow-chart.

ii) *Multi-layer polygons were combined* into one record by computing a weight for each layer within the polygon. The layer weight was basal area if all layers within the polygon had a positive basal area; otherwise live stems/ha was used.

iii) *Species composition for the overall polygon was* estimated by combining layer-level species composition and weight.

iv) *Height and age were averaged for each* species where at least one height/age estimate was available for that species. The averages were weighted using layer weight and species percent within the layer.

v) *Species rank was assigned* based on species proportion, but was randomly assigned when two or more species had the same proportion. The species with height estimates were chosen as the leading species when two species were equivalent and one did not have a height estimate.

vi) The following items were summed (without weight) across layers[7]:

- Crown closure
- Basal area
- Stems/ha (live and dead)
- Number of tall fir trees
- Volume

The Estimation Phase attributes required for the Boston Bar protocol were:

- Map/stand identifier
- Polygon area
- Species composition
- Height, age, and site index of the leading species
- Volume
- Stems/ha (live and dead)
- Basal area
- Lorey height
- Number of tall fir trees/ha

2.5.2 Ground Sampling Phase Database

Problem 2. The Ground Sampling data need to be obtained, and some computations and corrections need to be done.

Lorey height was based on full-measured trees with no broken tops. JST compiled number of tall fir trees/ha (number/ha of live Douglas-fir at least 25 m tall [actual height]) and the different volumes and dollar value/ha (Figure 4).

[7] No weight is required for these attributes because the sum in all layers is the total attribute for the polygon.

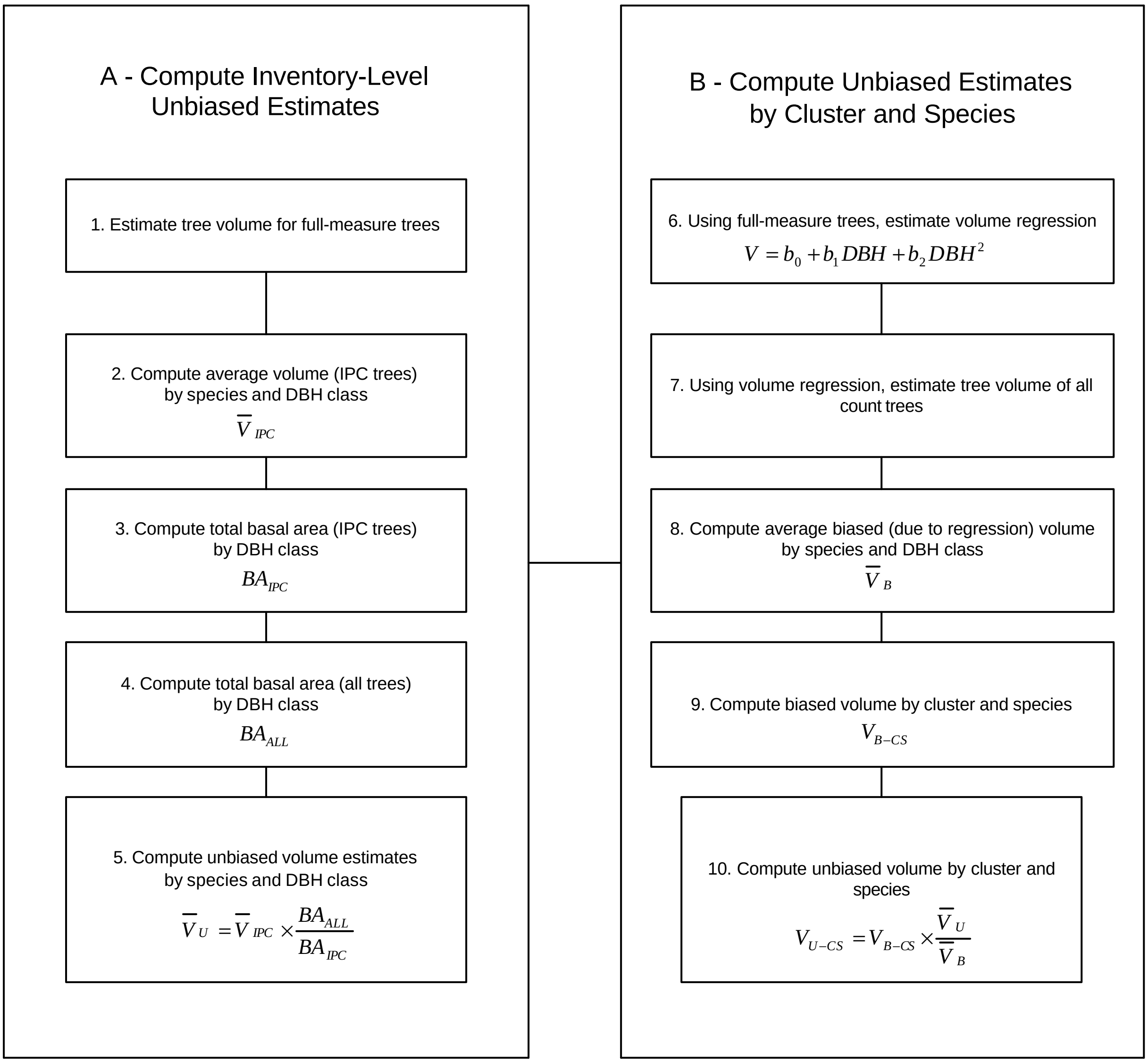


Figure 4. JST volume and value compilation algorithm.

2.6 BOSTON BAR ADJUSTMENT

2.6.1 Volume Adjustment – Overview

Problem 3.	The relationship between several volumes (whole-stem volume, whole-stem volume minus top and stump, etc.) at different utilization levels (4cm+, 7.5cm+, etc.) needs to be determined.

This process requires examining five different volumes:

[1] whole-stem volume/ha less top and stump, decay, waste, and breakage (net merch volume)
[2] whole-stem volume/ha less top and stump, decay, and waste
[3] whole-stem volume/ha less top and stump, and decay
[4] whole-stem volume/ha less top and stump
[5] whole-stem volume/ha

and five utilization levels (4cm+, 7.5cm+, 12.5cm+, 17.5cm+, and 22.5cm+) for both live and dead volume. Volume components within a utilization level can be obtained by subtraction. Adjusting volume components at one utilization level (net merchantable [merch] volume at 4cm+), before deducing all other volumes at all other utilization levels, is easier than doing individual adjustments while maintaining compatibility among adjustments. The volumes were used to deduce the relationships necessary for making all these amounts correctly proportional to each other.

The Estimation Phase volume was adjusted to five different utilization levels for both live and dead volume. The adjustment process described in this report (Figure 5) ensures that all logical relationships among volumes and utilization levels are respected.

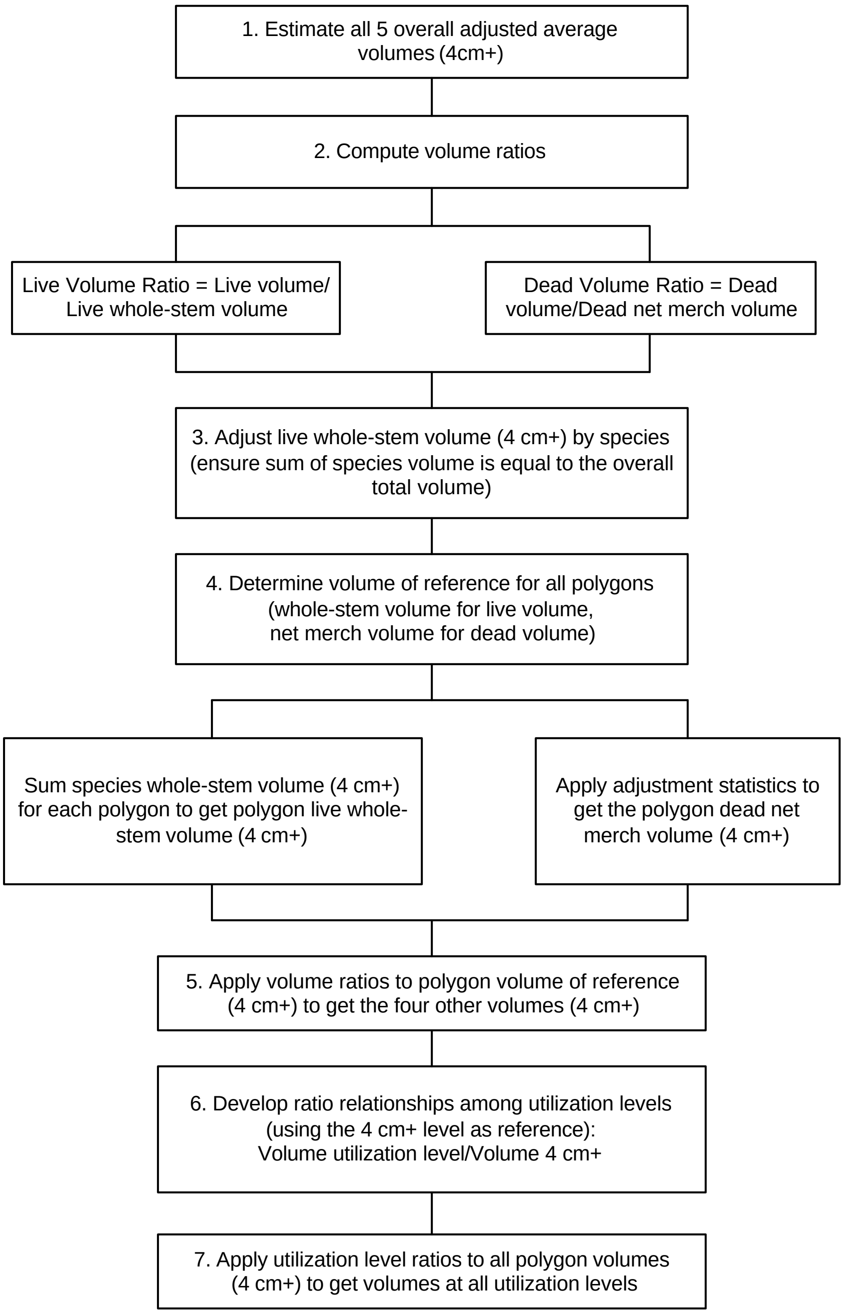


Figure 5. Volume adjustment flow-chart.

2.6.2 Overall Volume Adjustments – 4cm+

Live and dead volumes were examined at the 4cm+ utilization level as a "base case". The Ground Sampling Phase data were used to break down volume into five distinct components before adjusting the individual components:

a. net merch volume
b. breakage
c. waste
d. decay
e. top and stump

These components were calculated for each polygon in the population, using volumes [1] to [5]:

[a] whole-stem volume/ha less top & stump, decay, waste, and breakage = net merch volume = [1]
[b] breakage volume/ha = [2] – [1]
[c] waste volume/ha = [3] – [2]
[d] decay volume/ha = [4] – [3]
[e] top and stump volume/ha = [5] – [4]

The relationships between volumes ([1] to [5] as defined on p.8) and components ([a] to [e]) are illustrated in Figure 6.

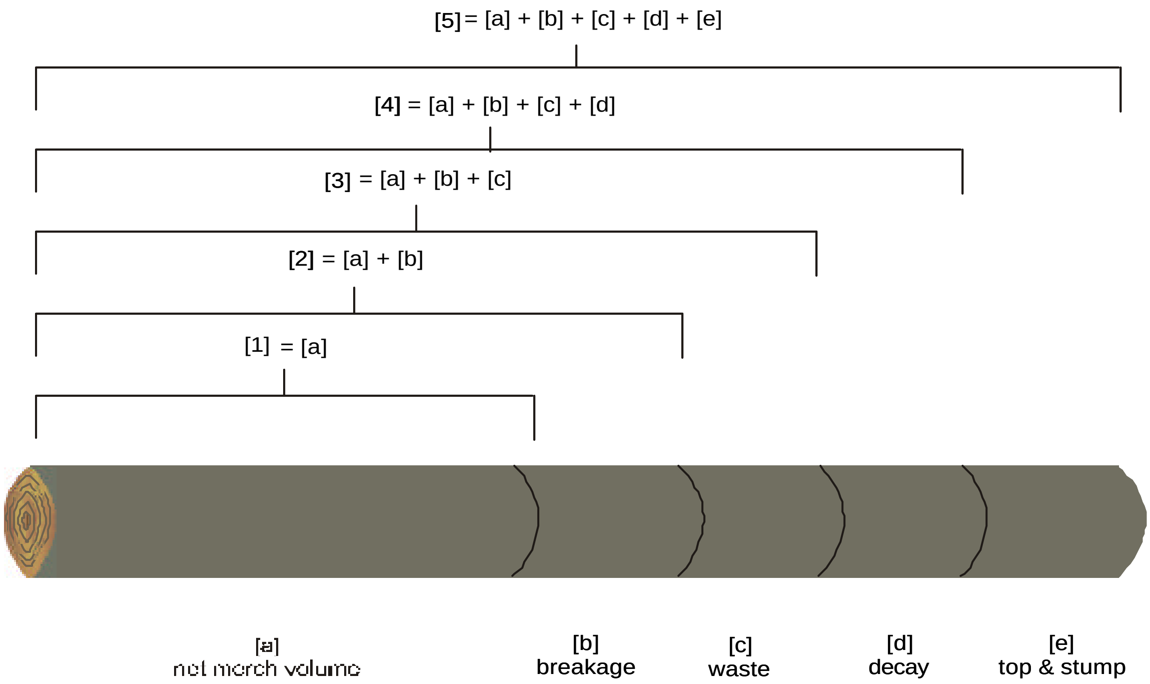


Figure 6. Relationship between volumes and volume components.

A three-step adjustment procedure was followed to maintain a logical relationship among volumes (4cm+):

i) By subtraction, break down the Ground Sampling Phase whole-stem volume/ha (4cm+) into five distinct volume components (listed previously [a]-[e]) for all sampled polygons.
ii) Adjust each component proportionally to the difference between the sample (Ground Sampling Phase) and the population (Estimation Phase). This gives an adjusted volume for each component.
iii) Use these adjusted volume components to get all five adjusted average volumes, and the proportion compared to the whole-stem volume.

This procedure is illustrated in Section 3.3 for live volume and Section 3.7 for dead volumes.

2.6.3 Total Species Volume and Species Percentage

Problem 4.	The species volume totals need to be adjusted individually, and they need to sum up to the best estimate of the overall volume total.

The Estimation Phase and Ground Sampling Phase data were matched by polygon and species group. When a species occurred in the Estimation Phase but was not recorded in the Ground Sampling Phase, the ground-sampled volume was assumed to be zero.[8] When a species occurred in the Ground Sampling Phase but was not recorded in the Estimation Phase, the species was dropped from the analysis. This methodology was adopted because there is no current mechanism for introducing species not seen by the photo-interpreter into the Adjustment Phase.[9]

Total whole-stem volume (4cm+) was first computed for each species individually. These volumes were then multiplied by a factor to ensure that the sum of the species' whole-stem volume matched the overall whole-stem volume computed at the previous step. This process is illustrated in Section 3.4.

2.6.4 Polygon Level Volumes – 4cm+

Problem 5.	The adjustment methods for species volume need to be applied at the polygon level so that polygon species percentage and volume can be adjusted. Volumes other than whole-stem volume also need to be computed.

For live volume, the adjusted whole-stem volume ([5]) was computed in each polygon and species using the process described in the previous section.

The four other volumes for the polygon are also needed. Therefore, the ratio between overall live whole-stem volume and the other volumes ([1]/[5], [2]/[5], [3]/[5], and [4]/[5]) was applied to the polygon-level live whole-stem volume (4cm+) to estimate live volumes [1] to [4] (4cm+). This process is illustrated in Section 3.5.

For dead volume, the same basic process was used but with another base. The base volume was adjusted net merch volume ([1]) as obtained from adjusted [a]. This was due to the problems with short

[8] While not present in the ground sample, the species could have occurred elsewhere in the polygon outside the ground sample.

[9] There are several ways to handle this problem but none have been tested yet. The problem is minor for Lignum's IFPA area.

trees and other factors that make the whole-stem volume less reliable as a base. Ratios between overall net merch volume and the four other volumes ([2]/[1], [3]/[1], [4]/[1], and [5]/[1]) were applied to the polygon level dead net merch volume (4cm+) to estimate dead volumes [2] to [5] (4cm+). This process is illustrated in Section 3.8.

2.6.5 Polygon Level Volumes – Other Utilization Levels

> Problem 6. The relationships among utilization levels in a polygon need to be correlated with tree size.

Polygon level volumes were estimated at five different utilization levels: 4cm+, 7.5cm+, 12.5cm+, 17.5cm+, and 22.5cm+. To maintain logical relationships among utilization levels, a ratio relationship was assumed between the 4cm+ and the other utilization levels. To make these relationships more logical for trees with different sizes, ratio relationships were developed by quadratic mean diameter (QMD).

First, ratios were derived by QMD group: <8 cm, 8 to 16 cm, 16 to 24 cm, and >24 cm. These ratios were applied at the polygon level by calculating the polygon level QMD and interpolating between adjacent ratios. Where the QMD was greater than 24 cm or less than 8 cm, the ratio corresponding to the QMD group was applied without interpolation.

A preliminary analysis showed the ratios for whole-stem volume to be different from the ratios for other volumes. Therefore, separate ratios were estimated for whole-stem volumes versus volumes [1] to [4]. These ratios were applied to the 4cm+ polygon-level volumes [1] to [5] to estimate volumes at all utilization levels (Figure 7). This process is illustrated in Section 3.6 for live volumes and Section 3.9 for dead volumes.

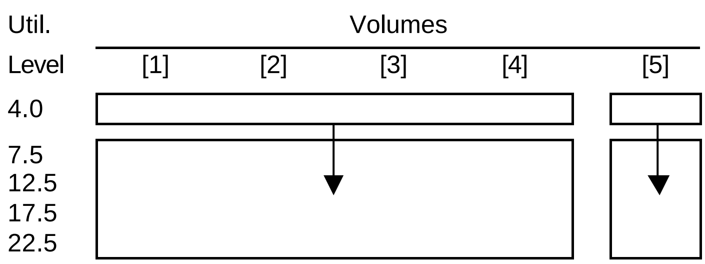


Figure 7. Volume estimation at all utilization levels.

> Problem 7. Other attributes need to be adjusted even if they have not been photo-interpreted.

2.6.6 Basal Area and Stems/ha

Live basal area was available in the Ground Sampling Phase database for all five utilization levels. However, only the 4cm+ utilization level was adjusted in the analysis. If it were necessary to have other utilization levels, they would be coordinated in the same way as volume was handled.

Dead basal area was not available in the Estimation Phase database, therefore we used the estimated live basal area as a substitute for estimated dead basal area (on the assumption that dead tree basal area might be proportional to live tree basal area).

In general, there is no problem substituting some other estimated item. Usually, we adjust an estimated attribute from the same measured attribute. For example, if the estimated stand basal area is better correlated to stand volume than the photo-interpreter's direct estimate of stand volume, we could ignore the estimated stand volume and do a regression relating estimated stand basal area and measured stand volume. There is no reason for estimated and measured items to necessarily be in the same units or have the same definitions.

Both live and dead stems/ha were available in the Estimation Phase database, and the Ground Sampling Phase stems/ha were adjusted based on the corresponding estimate.

2.6.7 Height, Site Index, and Age

Lorey height in the Ground Sampling Phase was based on all fully measured trees (no broken tops). Ground Sampling average breast-height (BH) age was based on the BH age of the random tree. Because of the multiple layers within a polygon, height and BH age were available for up to five species within a polygon.

The MSRM recommends that height, age, and site index of the leading (or secondary) species be consistent with the height-age equations. To achieve this, two of the three variables must be adjusted, while the third one is derived from *SiteTools, version 3.2i*. Height and site indices were adjusted because they are the most important variables. The final adjusted total age and BH age were later derived from *SiteTools, version 3.2i* using the adjusted leading (or secondary) species, adjusted height, and adjusted site index.

Height and site indices were obtained by using the Ground Sampling Phase average height and average site index of the Top, Leading, or Secondary (TLS) site trees and the Estimation Phase height and age estimates. Adjustment statistics were calculated by species group. Only four species groups (At, Fdi, Pl, and Sx) had enough observations to obtain adjustment relationships. The overall adjustment for minor species was calculated by grouping all those observations into one data set (shown as "Others" in Table 11 and 12).

In a few cases (3.3% of all cases), either the adjusted leading species or the secondary species had no Estimation Phase height or site index to be adjusted. For these species, the Lorey height and average BH age were used to derive an estimated site index and total age from *SiteTools, version 3.2i*.

2.6.8 Tall Fir Trees

Estimated number of tall fir trees/ha was available in the Estimation Phase database. Number of tall fir trees/ha (> 25 m) was also available in the Ground Sampling Phase database for all five utilization levels. However, all tall fir trees were 22.5 cm DBH or more; therefore, numbers for all five utilization levels were identical. Only one number is presented in this report.

2.6.9 Dollar Value/ha

Dollar value/ha was computed for the Ground Sampling Phase for all five utilization levels. An estimated value, however, was not available in the Estimation Phase database; therefore estimated volume was substituted for estimated dollar value. As in the case of volume, value/ha was first adjusted at the 4cm+ utilization level. Ratio relationships by QMD group were used to derive dollar value/ha at all other utilization levels as described in Section 2.6.5.

2.7 BOSTON BAR RE-APPORTIONMENT BY LAYER

Adjusted total polygon estimates were assigned to layers using the unadjusted photo-interpreted proportions of each layer within a polygon. An example to illustrate the process is provided in Appendix I. Since no field information is collected at the layer level, layer attributes have no statistical validity. Therefore, it is suggested that for all analyses, the polygon-level attributes be used.

2.8 MSRM DATABASE PREPARATION

For each polygon, the tallest layer with more than 10% crown closure was identified. The attributes for that layer were assumed to be the attributes for the entire polygon.

The attributes required for the MSRM standard adjustment procedure were:

- Map/stand identifier
- Public Sustained Yield Unit (PSYU)
- Forest Inventory Zone (FIZ)
- Polygon area
- Species composition
- Height and age of the leading species
- Crown closure
- Stocking class

For the MSRM standard adjustment procedure only height and age of the leading species and volume were adjusted.

2.9 MSRM ADJUSTMENT PROCEDURE

Height and age of the leading species were adjusted. Before adjustment, each species was translated into one of the 16 commercial tree species groups recognized by the MOF. Estimation Phase and Ground Sampling Phase data were matched by mapsheet, polygon number, and species group. The only Ground Sampling Phase clusters that were selected were ones that had a top height and age for the leading species group in the Estimation Phase. Only the Top, Leading, and Second (TLS) site trees were used to calculate the average Ground Sampling height and age. The ratio of means method was used to adjust the Estimation Phase values.

Once height and age were adjusted, an attribute-adjusted volume was generated using *Batch VDYP, version 6.6d*. NVAF-adjusted net merchantable volume (whole-stem volume minus top, stump, decay, waste, and breakage) was used. Utilization level was 12.5 cm+ for Pl-leading stands and 17.5 cm+ for all other stands. Deciduous volumes were not removed from volume calculations. The VDYP attribute-adjusted volume was adjusted using the ratio of means method between Ground Sampling and attribute-adjusted volumes. A separate ratio was calculated for Pl stands (utilization level 12.5 cm+) and other species (utilization level 17.5 cm+).

3. BOSTON BAR PROTOCOL RESULTS

3.1 CHECK-CRUISE COMPARISON

Problem 8. Ground Sampling measurements need to be checked to make sure they are accurate.

The check-cruise measurements were computed and compared to the field crew measurements on the same plots. This comparison must be made for every inventory because this comparison reflects the quality of individual crews. If field crews are making more than trivial field errors, an additional correction must be made to any inventory results.

The results in the Lignum field work were very close to the check-cruise numbers (less than 1% difference was found[10] in the computed results). No correction was made for this small difference. This verifies that the field work was accurate (when compared to the work of a check cruiser).

3.2 NVAF VOLUME CORRECTION

Problem 9. Volume needs to be corrected for taper, measurement, and other errors.

A valid statistical sample of trees was felled and destructively sampled to calibrate the measurement process. This process corrects for taper, measurement, and other errors possible in the volume calculation process. This yields a statistically valid comparison between check-cruiser measurements and the actual tree volumes. For cruiser-estimated net volumes, the correction multipliers were 0.97356 for live trees, and 0.89055 for dead trees.

3.3 LIVE VOLUMES – 4CM+

The adjustment statistics for the base net merchantable volume and its individual components at the 4cm+ utilization level are shown in Table 3 (scattergrams are in Appendix II). The adjusted population component averages were predicted using the ratio of means method. The resulting five volumes were obtained by summing the components, as seen in Table 4.

[10] This comparison was done by Kim Iles, *PhD*, a consulting biometrician working on the project.

Table 3. Component adjustment statistics (live, 4cm+).

Volume Component	Area (ha)	Population Map Avg. (m^3/ha)	Sample Size	Sample Grnd. Avg. (m^3/ha)	Sample Map Avg. (m^3/ha)	Sample Ratio of Means	Sample R^2 (%)	Population Adj. Map Avg. (m^3/ha)
[a] Net merch volume	545,971	141.1	353	**108.1**	154.5	0.699	48	**98.7**
[b] Breakage	545,971	141.1	353	5.4	154.5	0.035	47	4.9
[c] Waste	545,971	141.1	353	0.2	154.5	0.001	6	0.2
[d] Decay	545,971	141.1	353	1.5	154.5	0.010	12	1.4
[e] Top&Stump	545,971	141.1	353	29.1	154.5	0.188	8	26.6

Note: Bold, coloured numbers can be followed to other tables and examples.

For net merch volume 141.1 x (108.1/154.5) = 98.7. The logic is that if the 353 sampled polygons had 69.9% (108.1/154.5) measured volume of what was estimated, the non-sampled polygons would contain the same *proportion* of measured volume.

Table 4. Adjusted live volumes at 4cm+ utilization level.

	Volume	Sample Ground Avg. (m^3/ha)	Adjusted Pop. Avg. (m^3/ha)	Proportion of Whole-Stem Volume
[1]	Vol/ha less top and stump, decay, waste, breakage, top & stump	**108.1**	**98.7**	**0.749**
[2]	Vol/ha less top and stump, decay, and waste	113.5	103.6	**0.786**
[3]	Vol/ha less top and stump and decay	113.7	103.8	**0.788**
[4]	Vol/ha less top and stump	115.2	105.2	**0.798**
[5]	Whole-stem volume/ha	144.3	**131.8**	1.000

The sample ground average volume [2] is the sum of ground net merch volume (108.1 m^3/ha) and ground breakage (5.4 m^3/ha), for a total of 113.5 m^3/ha. Similarly, the adjusted population average is the sum of 98.7 m^3/ha and 4.9 m^3/ha, for a total of 103.6 m^3/ha. The proportion of whole-stem volume is then 103.6/131.8 = 0.790.

3.4 Species Volume Adjustment

Volume adjustment statistics by species are shown in Table 5 (scattergrams are in Appendix III). Individual regressions were estimated for lodgepole pine (Pl), Douglas-fir (Fdi), interior spruce (Sx), and aspen (At). Species with less than 10 observations were grouped under “Others”. These included cottonwood (Ac), balsam (B), cedar (Cw), birch (E), hemlock (Hw), white-bark pine (Pa), and Ponderosa pine (Py).

Because the Estimation Phase data did not always contain the same species as the Ground Sampling Phase data, the sum of the sample ground averages by species is slightly less than the overall sample ground average (135.4 m^3/ha by species [Table 5], 144.3 m^3/ha overall [Table 4]). As expected, the sum of the individual species adjusted population Estimation Phase average (129.2 m^3/ha) did not equal the overall adjusted population Estimation Phase average (131.7 m^3/ha). The balanced species total volume was then obtained by multiplying the unbalance species total by 1.020 (= 131.7/129.2).

Rather than adjusting individual species volumes to get the overall total volume, a simpler method is to adjust the ground average (141.1 x 135.4/147.6 =129.4). This approach however does not take advantage of the fact that ground sample and photo estimates are related differently for each species. Therefore, adjusting individual species volume to obtain overall total volume is preferred.

When the individual regressions were applied to each species in all the polygons, the sum of all the volumes did not add up to 129.2 m^3/ha because some species volumes had to be constrained to 0 due to the negative intercept. The actual total of all polygon volumes was 130.1 m^3/ha. Therefore, a multiplicative adjustment factor (131.8/130.1.=1.013) was applied so that the overall average polygon volume balanced to the predicted average 131.8 m^3/ha.

Table 5. Species volume adjustment statistics (live whole-stem volume, 4cm+).

Species Group	Population Map Avg. (m^3/ha)	Sample						Population Map			
		Size	Ground Avg. (m^3/ha)	Map Avg. (m^3/ha)	Ratio of Means	R^2 (%)	Adjustment Intercept	Adjustment Slope	Adjusted (m^3/ha)	Balanced (m^3/ha)
Pl	57.7	249	55.6	62.1	0.896	38	4.5	0.823	51.7	52.7
Fdi	60.7	206	48.9	63.8	0.766	33	**-0.9**	**0.780**	46.5	47.5
Sx	13.6	81	21.5	15.1	1.431	21	0.0	1.431	19.5	19.9
At	7.5	53	5.1	4.7	1.084	38	**-1.0**	**1.301**	8.2	8.3
Others	1.5	17	4.3	1.9	2.225	31	-1.7	3.121	3.3	3.4
Total	*141.1*		*135.4*	*147.6*					*129.2*	***131.8***

For Pl, (57.7 x 0.896) x (131.8 / 129.2) = 52.7 m^3/ha.

Example 3.4:

The example polygon had a species composition of 60% At and 40% Fdi, and an estimated total volume of 140 m^3/ha. The species Estimation volume for the example polygon is 84 m^3/ha (140 x 60%) for species At and 56 m^3/ha (140 x 40%) for species Fdi. The adjusted live whole-stem volume can be estimated, using the adjustment regressions from Table 5, as:

At = [**-1.0** + **1.301** x 84] x 1.013 = 108.3 x 1.013 = **109.7** m^3/ha
Fdi = [**-0.9** + **0.780** x 56] x 1.013 = 42.8 x 1.013 = **43.3** m^3/ha

for a total volume of **109.7** + **43.3** = **153.0** m^3/ha

This gives an adjusted species composition of:

28.3% Fdi (= 43.3/153.0)
71.7% At (= 109.7/153.0)

3.5 POLYGON LIVE VOLUMES – 4CM+

Polygon-level whole-stem volume at 4cm+ utilization level was obtained by summing the whole-stem volume (4cm+) of all species present in the polygon. The other four volumes at utilization level 4cm+ were obtained by multiplying the polygon-level whole-stem volume by the proportion of whole-stem volume given in Table 4.

Example 3.5:
The adjusted whole-stem volume (4cm+) for species At was 109.7 m^3/ha and 43.3 m^3/ha for species Fdi. Therefore the whole-stem volume for the polygon was:

[5] = **109.7** + **43.0** = **153.0** m^3/ha

The other adjusted volumes can be estimated, using the whole-stem proportion from Table 4, as:

[1]: 153.0 x **0.749** = **114.6** m^3/ha
[2]: 153.0 x **0.786** = **120.3** m^3/ha
[3]: 153.0 x **0.788** = **120.6** m^3/ha
[4]: 153.0 x **0.798** = **122.1** m^3/ha

3.6 Polygon Live Volumes – Other Utilization Levels

Ratio relationships were derived to adjust live volumes at 4cm+ utilization to the other utilization levels. As expected, these relationships varied greatly by QMD group (Table 6; Figure 8).

Table 6. Relationships among utilization levels by QMD group (live volumes).

	Live Net Merch Volume (types [1]-[4])				Live Whole-Stem Volume (type [5])			
Util. Level	< 8 cm	8-16 cm	16–24 cm	≥ 24 cm	< 8 cm	8-16 cm	16–24 cm	≥ 24 cm
4.0cm+	1.000	1.000	1.000	**1.000**	1.000	1.000	1.000	**1.000**
7.5cm+	1.000	1.000	1.000	**1.000**	0.560	0.950	0.997	**1.000**
12.5cm+	0.714	0.930	0.995	**1.000**	0.232	0.750	0.959	**0.997**
17.5cm+	0.312	0.667	0.870	**0.984**	0.109	0.523	0.815	**0.978**
22.5cm+	0.226	0.472	0.662	**0.925**	0.078	0.375	0.614	**0.917**

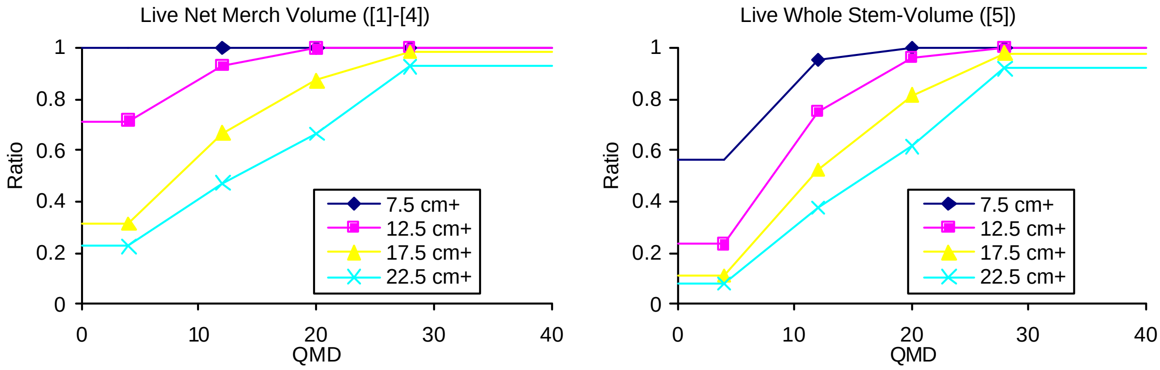


Figure 8. Relationship between utilization level and QMD group (live).

Using the adjusted polygon level volumes at the 4cm+ utilization level (calculations shown in Section 3.5) and the relationship ratios among utilization levels (Table 6), the adjusted polygon volumes can be derived for all five volumes and all utilization level combinations. The net merch volume relationship ratios in Table 6 are applied to volumes [1] to [4] while the whole-stem volume ratios are applied to whole-stem volume only (volume [5]).

Example 3.6:

The QMD for the example polygon is 37.3 cm, which means using the ≥24 cm QMD group ratios. The volumes at all utilization levels are then:

Volume [1]-[4]:

Util. Level	Ratio	[1]	[2]	[3]	[4]
4cm+	**1.000**	**114.6** m^3/ha	**120.3** m^3/ha	**120.6** m^3/ha	**122.1** m^3/ha
7.5cm+	**1.000**	114.6 m^3/ha	120.3 m^3/ha	120.6 m^3/ha	122.1 m^3/ha
12.5cm+	**1.000**	114.6 m^3/ha	120.3 m^3/ha	120.6 m^3/ha	122.1 m^3/ha
17.5cm+	**0.984**	112.9 m^3/ha	118.4 m^3/ha	118.7 m^3/ha	120.2 m^3/ha
22.5cm+	**0.925**	106.1 m^3/ha	111.3 m^3/ha	111.6 m^3/ha	113.0 m^3/ha

Volume [5]:

Util. Level	Ratio	[5]
4cm+	**1.000**	**153.0** m^3/ha
7.5cm+	**1.000**	153.0 m^3/ha
12.5cm+	**0.997**	152.5 m^3/ha
17.5cm+	**0.978**	149.6 m^3/ha
22.5cm+	**0.917**	140.3 m^3/ha

3.7 DEAD VOLUMES – 4CM+

The adjustment statistics for dead volume components are shown in Table 7 (scattergrams are in Appendix IV). Reconstructed volumes are shown in Table 8. Dead volume was not estimated in the Estimation Phase, and thus the estimation averages are from live volumes.

Table 7. Component adjustment statistics (dead, 4cm+).

Volume Component	Population		Sample					Population
	Area (ha)	Map Avg. (m^3/ha)	Size	Grnd. Avg. (m^3/ha)	Map Avg. (m^3/ha)	Ratio of Means	R^2 (%)	Adj. Map Avg. (m^3/ha)
[a] Net Merch Volume	545,971	141.1	353	**13.1**	154.5	0.084	3	**11.9**
[b] Breakage	545,971	141.1	353	2.0	154.5	0.013	3	1.8
[c] Waste	545,971	141.1	353	2.1	154.5	0.013	0	1.9
[d] Decay	545,971	141.1	353	10.9	154.5	0.071	1	10.0
[e] Top & Stump	545,971	141.1	353	7.9	154.5	0.051	2	7.2

All these corrections are based on the simple ratio (141.1/154.5) applied to the sample ground average. For instance, net merch volume is 13.1 x (141.1/154.5) = 11.9 m^3/ha.

Table 8. Adjusted dead volumes at 4cm+ utilization level.

	Volume	Sample Ground Avg. (m^3/ha)	Adjusted Pop. Avg. (m^3/ha)	Proportion of Net Merch Volume
[1]	Vol/ha less top and stump, decay, waste, breakage	**13.1**	**11.9**	1.000
[2]	Vol/ha less top and stump, decay, and waste	15.1	13.7	1.159
[3]	Vol/ha less top and stump and decay	17.2	15.7	1.32
[4]	Vol/ha less top and stump	28.1	20.7	2.157
[5]	Whole-stem volume/ha	36.0	27.9	2.762

The sample ground average volume [2] is the sum of ground net merch volume (13.1 m^3/ha) and ground breakage (2.0 m^3/ha), for a total of 15.1 m^3/ha. Similarly, the adjusted population average is the sum of 11.9 m^3/ha and 1.8 m^3/ha, for a total of 13.7 m^3/ha. The proportion of net merch volume is then 13.7/11.9 = 1.159.

3.8 Polygon Dead Volumes – 4cm+

Polygon-level dead net merch volume at 4cm+ utilization level was obtained by applying the ratio of means method to the live Estimation volume (Table 7). The other four volumes at utilization level 4cm+ were obtained by multiplying the polygon-level net merch volume by the proportion to net merch volume given in Table 8.

Example 3.8:
The adjusted dead net merch volume (4cm+) for the example polygon was:

[1] = 140 x 0.084 = **11.8** m^3/ha

The other adjusted volumes can be estimated, using the net merch volume proportion from Table 8, as:

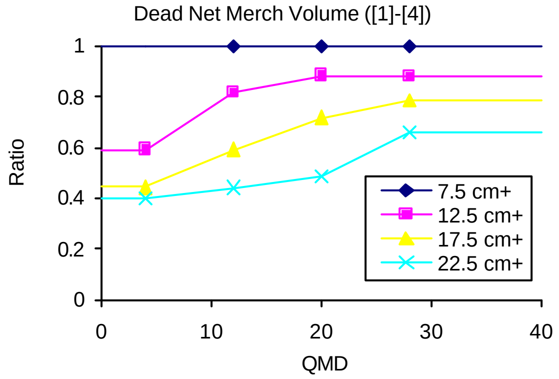
[2]: 11.8 x 1.159 = **13.6** m^3/ha
[3]: 11.8 x 1.32 = **15.5** m^3/ha
[4]: 11.8 x 2.157 = **25.4** m^3/ha
[5]: 11.8 x 2.762 = **32.5** m^3/ha

3.9 Polygon Dead Volumes – Other Utilization Levels

Ratio relationships were derived to adjust dead volumes at 4cm+ utilization to the other utilization levels. As with live volumes, these relationships varied greatly by QMD group; however differences between utilization levels for whole-stem volume versus net merch volume were not as pronounced (Table 9, Figure 9).

Table 9. Relationships among utilization levels by QMD group (dead volumes).

Util.Level	Dead Net Merch Volume (types [1]-[4])				Dead Whole-Stem Volume (type [5])			
	< 8 cm	8-16 cm	16–24 cm	≥ 24 cm	< 8 cm	8-16 cm	16–24 cm	≥ 24 cm
4.0cm+	1.000	1.000	1.000	**1.000**	1.000	1.000	1.000	**1.000**
7.5cm+	1.000	1.000	1.000	**1.000**	0.725	0.891	0.979	**0.950**
12.5cm+	0.592	0.815	0.883	**0.880**	0.458	0.704	0.788	**0.911**
17.5cm+	0.444	0.592	0.717	**0.785**	0.390	0.560	0.656	**0.796**
22.5cm+	0.401	0.441	0.488	**0.659**	0.293	0.412	0.492	**0.665**



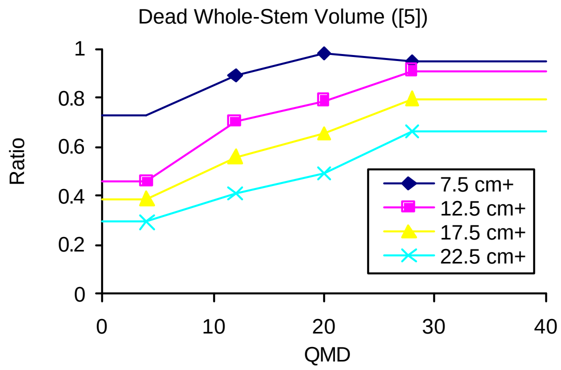


Figure 9. Relationship between utilization level and QMD group (dead).

Using the adjusted polygon-level dead volumes at 4cm+ utilization level (3.8) and the relationship ratios among utilization levels (Table 9), the adjusted polygon-level dead volumes can be derived for all five volumes and five utilization level combinations. The net merch volume relationship ratios are applied to volumes [1] to [4] while the whole-stem volume ratios are applied to whole-stem volume only (volume [5]).

Example 3.9

The QMD for the example polygon is 37.3 cm, which means using the ≥24 cm QMD group ratios. The dead volumes at all utilization levels are then:

Volumes [1]-[4]:

Util. Level	Ratio	[1]	[2]	[3]	[4]
4cm+	**1.000**	**11.8** m^3/ha	**13.6** m^3/ha	**15.5** m^3/ha	**25.4** m^3/ha
7.5cm+	**1.000**	11.8 m^3/ha	13.6 m^3/ha	15.5 m^3/ha	25.4 m^3/ha
12.5cm+	**0.880**	10.4 m^3/ha	12.0 m^3/ha	13.7 m^3/ha	22.3 m^3/ha
17.5cm+	**0.785**	9.3 m^3/ha	10.7 m^3/ha	12.2 m^3/ha	19.9 m^3/ha
22.5cm+	**0.659**	7.8 m^3/ha	9.0 m^3/ha	10.2 m^3/ha	16.7 m^3/ha

Volume [5]:

Util. Level	Ratio	[5]
4cm+	**1.000**	**32.5** m^3/ha
7.5cm+	**0.950**	30.9 m^3/ha
12.5cm+	**0.911**	29.6 m^3/ha
17.5cm+	**0.796**	25.9 m^3/ha
22.5cm+	**0.665**	21.6 m^3/ha

3.10 HEIGHT, SITE INDEX, AND AGE

3.10.1 Lorey Height and Average Breast-height Age

There was a moderate correlation between the Estimation Phase and the Ground Sampling Phase Lorey height (Table 10, Appendix V) and a regression was used. A ratio of means method was used on average age since the relationship was poor.

After adjustment, Lorey height decreased by almost 1.5 m (9%), while the average age decreased by only 3 years (3%). This shows that the unadjusted average age was more accurate than the unadjusted average height in the Estimation Phase database.

Table 10. Lorey height (m) and average breast-height age (yrs) adjustment statistics.

Attribute	Population		Sample					Population		
	Area (ha)	Map Avg. (m)	Size	Ground Avg. (m)	Map Avg. (m)	Ratio of Means	R^2	Adjustment Intercept	Adjustment Slope	Adj. Map Avg. (m)
Lorey Height (m)	545,971	17.0	342	15.4	17.0	0.911	41%	-0.5	0.940	15.5
Avg BH Age (yrs)	545,971	104.0	311	100.2	103.0	0.972	22%	0.0	0.972	101.1

Lorey height is (17.0 x 0.940) –0.5 = 15.5 m.

Example 3.10.1:
The Lorey height for the example polygon is 23.4 m and the average age is 110 yrs. Therefore the adjusted values become:

Lorey height: **-0.5** + (23.4 x **0.940**) = 21.5 m

Average age: **0.0** + (110 x **0.972**) = 106.9 yrs

3.10.2 Height, Site Index, Total Age, and Breast-height Age

The adjusted heights were on average very close to the Estimation Phase heights, except for spruce (Table 11, Appendix VI). Spruce heights tended to be overestimated by about 4%. The overall height adjustment for other species combined was marginal, at 0.4 m (as shown under the label "Others").

Table 11. Height (m) adjustment statistics.

Species Group	Population Map Avg. (m)	Sample Size	Ground Avg. (m)	Map Avg. (m)	Ratio of Means	R^2	Adjustment Intercept	Adjustment Slope	Population Adj. Map Avg. (m)
Pl	14.9	197	15.7	15.1	1.041	60	1.5	0.943	15.5
Fdi	19.3	146	19.48	19.3	1.008	24	0.0	1.008	19.5
Sx	20.4	46	21.33	22.3	0.955	30	2.6	0.840	19.5
At	15.9	17	14.16	15.1	0.935	61	0.1	0.929	14.8
Others	17.1	412	17.72	17.4	1.020	50	1.4	0.939	17.5

For Pl, (14.9 x 0.943) + 1.5 = 16.0 m.

Example 3.10.2a:
The example polygon has a height of 27 m for species At and 18 m for species Fdi. The adjusted heights are then:

At: **0.1** + (27 x **0.929**) = 25.2 m

Fdi: **0.0** + (18 x **1.008**) = 18.1 m

Site index increased after adjustment (Table 12, Appendix VI). The average increase was 2.0 m (16%). The site index estimates increased from 12-13 m to 14-15 m. The site index adjustment does not correct for repression in Pl stands. Therefore the adjusted site index is not really a good indicator of what the productivity of these stands might be after they are harvested.

Table 12. Site index (m) adjustment statistics.

Species Group	Population Map Avg. (m)	Sample Size	Sample Ground Avg. (m)	Sample Map Avg. (m)	Sample Ratio of Means	Sample R^2 (%)	Population Adjustment Intercept	Population Adjustment Slope	Population Adj. Map Avg. (m)
Pl	11.9	197	14.0	12.0	1.168	37	1.1	1.077	13.9
Fdi	12.2	146	13.8	12.1	1.139	22	0	1.139	13.9
Sx	12.5	46	14.8	13.0	1.142	24	0	1.247	14.3
At	13.3	17	18.0	13.8	1.312	2	0	1.312	17.4
Others	12.2	412	14.2	12.2	1.165	25	0	1.178	14.2

For Pl, (11.9 x 1.077) + 1.1 = 13.9 m.

Example 3.10.2b:
The example polygon has a site index of 18.0 m for species At and 14.6 m for species Fdi. The adjusted site indices are then:

At: **0.0** + (18.0 x **1.312**) = 23.6 m

Fdi: **0.0** + (14.6 x **1.139**) = 16.6 m

The adjusted height and site index estimates led to an average total age of 101 years and an average breast-height age of 92 years.

3.11 BASAL AREA, STEMS/HA, AND TALL FIR TREES

Dead basal area was not estimated in the Estimation Phase, thus the estimation attribute for both live and dead basal area was live basal area (Table 13, Appendix VII). Dead stems/ha was estimated in the Estimation Phase; however, preliminary analysis showed that it was uncorrelated to the Ground Sampling Phase estimate (correlation = 0.1%). Thus, the estimation average for both live and dead stems/ha was live stems/ha (Table 14, Appendix VII). The number of live and dead stems/ha increased substantially from the initial Estimation Phase estimates; dead stems/ha increased from 6 to 342 and live stems/ha increased from 846 to 1,201. The number of tall fir trees/ha was substantially overestimated in the Estimation Phase (Table 15, Appendix VII). This indicates that the initial Estimation Phase estimates for these attributes were unreliable.

Table 13. Basal area adjustment statistics.

Attribute	Population Area (ha)	Population Map Avg. (m^2/ha)	Sample Size	Sample Ground Avg. (m^2/ha)	Sample Map Avg. (m^2/ha)	Sample Ratio of Means	Sample R^2 (%)	Population Adjustment Intercept	Population Adjustment Slope	Population Adj. Map Avg. (m^2/ha)
Live BA/ha	545,971	22.5	353	20.5	24.5	0.837	42	-3.6	0.986	18.8
Dead BA/ha	545,971	22.5	353	6.2	24.5	0.253	2	0	0.253	5.7

Live basal area is 22.5 x (20.5/24.5) = 18.8 m^2/ha.

Table 14. Stems/ha and tall fir tree adjustment statistics.

Attribute	Population Area (ha)	Population Map Avg. (tr/ha)	Sample Size	Sample Ground Avg. (tr/ha)	Sample Map Avg. (tr/ha)	Sample Ratio of Means	Sample R^2 (%)	Population Adjustment Intercept	Population Adjustment Slope	Population Adj. Map Avg. (tr/ha)
Live Stems/ha	545,971	846	353	1,371	965	1.421	9	0.0	1.421	1,201
Dead Stems/ha	545,971	846	353	390	965	0.404	0	0.0	0.404	342
Tall Fir/ha	545,971	26	353	8	32	0.245	15	0/0	0.245	7

Live stems/ha is 846 x (1,371/965) = 1,201 trees/ha.

Example 3.11:
The basal area for the example polygon is 30 m^2/ha and the number of stems/ha is 275. Therefore, the adjusted live and dead basal area, and live and dead stems/ha, are:

Basal area – live: **-3.6** + (**30** x 0.986) = 26.0 m^2/ha
Basal area – dead: **0.0** + (**30** x 0.253) = 7.6 m^2/ha
Stems/ha – live: **0.0** + (**275** x 1.421) = 391 trees/ha
Stems/ha – dead: **0.0** + (**275** x 0.404) = 111 trees/ha

There were no Estimation Phase tall fir trees in the example polygon. Therefore the number of adjusted tall fir trees remained at 0/ha.

3.12 DOLLAR VALUE/HA

The adjustment statistics for dollar value/ha are shown in Table 15 (scattergram is in Appendix VIII). Because dollar value/ha was not estimated in the Estimation Phase, the population estimation average is the Estimation Phase volume.

Table 15. Dollar value/ha adjustment statistics.

Attribute	Population		Sample					Population		
	Area (ha)	Map Avg. (m^3/ha)	Size	Ground Avg. ($/ha)	Map Avg. (m^3/ha)	Ratio of Means	R^2	Adjustment Intercept	Adjustment Slope	Adj. Map Avg. ($/ha)
Dollars/ha	545,971	141.1	353	$6,203	154.5	40.133	45%	-$1,389	49.120	$5,542

Adjusted dollar value/ha is (141.1 x 49.120) – 1,389 = $5,542/ha.

Ratio relationships were derived to adjust dollar value/ha at 4cm+ utilization to the other utilization levels. As expected, these relationships varied greatly by QMD group (Table 16).

Table 16. Dollar value/ha relationships among utilization levels by QMD group.

Util. Level	< 8 cm	8-16 cm	16–24 cm	≥24 cm
4.0cm+	1.000	1.000	1.000	**1.000**
7.5cm+	1.000	1.000	1.000	**1.000**
12.5cm+	0.739	0.953	0.998	**1.000**
17.5cm+	0.338	0.741	0.913	**0.991**
22.5cm+	0.249	0.536	0.727	**0.947**

Using the polygon volume from the Estimation Phase, the polygon value at the 4cm+ utilization level can be estimated from the adjustment statistics in Table 15. Value at the other utilization levels can be derived based on the QMD of the polygon and the ratio relationships given in Table 16.

Example 3.12:
The example polygon has a volume of 140 m3/ha. The adjusted value/ha at the 4cm+ utilization level is therefore:

-1,389 + (140 x **49.12)** = $5,488/ha

Since the QMD for the example polygon is 37.3 cm (≥ 24 cm QMD group), values at the other utilization levels are:

Util. Level	Ratio	Value
7.5cm+	**1.000**	$5,488/ha
12.5cm+	**1.000**	$5,488/ha
17.5cm+	**0.991**	$5,438/ha
22.5cm+	**0.947**	$5,197/ha

4. MSRM STANDARD ADJUSTMENT PROCEDURE RESULTS

4.1 OVERVIEW

The MSRM standard adjustment procedure presented in this report used the MSRM volume compilation. MSRM layer ranking rules were used rather than Lignum's. NVAF-corrected volume was used.

4.2 HEIGHT AND AGE ADJUSTMENT

Height and age changed only marginally after adjustment (Table 17, Table 18, Appendix IX). For Fdi stands, height remained almost unchanged while total age decreased by 10 years (8%). In Pl stands, height increased by less only 0.4 m (3%), while total age decreased by six years (7%). In stands of other species, height decreased by 0.6 m (decrease of 3%), while age decreased by nine years (9%).

Table 17. Height adjustment statistics (MSRM standard adjustment procedure).

Species Group	Population Map Avg. (m)	Sample Size	Sample Ground Avg. (m)	Sample Map Avg. (m)	Sample Ratio of Means	Sample R^2	Population Adj. Map Avg. (m)
Pl	15.1	152	15.9	15.6	1.015	49%	15.4
Fdi	19.8	133	20.1	20.2	0.993	19%	19.7
Others	18.4	34	20.9	21.6	0.968	35%	17.8
Total	*17.4*	*319*	*18.2*	*18.2*	*0.999*		*17.4*

[1] For Pl, 15.1 x (20.1/20.2) = 15.4 m.

Table 18. Age adjustment statistics (MSRM standard adjustment procedure).

Species Group	Population Map Avg. (yrs)	Sample Size	Sample Ground Avg. (yrs)	Sample Map Avg. (yrs)	Sample Ratio of Means	Sample R^2	Population Adj. Map Avg. (yrs)
Pl	92	152	87	94	0.929	35%	85
Fdi	131	133	121	132	0.922	17%	120
Others	97	34	101	112	0.904	44%	88
Total	*109*	*319*	*103*	*113*	*0.923*		*100*

[1] For Pl, 81.5 x (87.2 /93.9) = 75.7 yrs.

4.3 VOLUME ADJUSTMENT RESULTS

Volume decreased substantially after adjustment (Table 19, Appendix IX). In Pl stands (utilization level of 12.5 cm+), volumes decreased by more than 40 m^3/ha (about 32%), while in other stands (utilization level of 17.5 cm+), volumes decreased by about 15 m^3/ha (14%).

Since the adjustment for height and age was small, the significant volume adjustment indicates that VDYP does not estimate initial stand volumes adequately in this area, especially for Pl-leading stands. More work is needed to identify the source of the VDYP over-estimation.

The Estimation Phase sample average was 16% above the population average for the 17.5 cm+ utilization level (127.1 versus 109.1 m^3/ha). We cannot yet explain this large difference, except to assume that it occurred by chance. Further investigation is required to identify the reason for the difference.

Table 19. Volume adjustment statistics (MSRM standard adjustment procedure).

Util. Level	Population Area (ha)	Population Map Avg. (m^3/ha)	Sample Size	Sample Ground Avg. (m^3/ha)	Sample Map Avg. (m^3/ha)	Sample Ratio of Means	Sample R^2	Population Adj. Map Avg. (m^3/ha)
12.5	244,221	125.6	173	86.4	128.0	0.675	42%	84.8
17.5	301,750	109.1	180	110.0	127.1	0.866	32%	94.5
Total	*545,971*	*116.6*	*353*	*98.3*	*127.6*	*1.298*		*90.1*

5. DISCUSSION

Both the Boston Bar and the MSRM adjustment protocols yielded similar results for height (Table 19). The overall average estimate for total age was also similar. The Boston Bar site index average however was 1.8 m (14%) higher than the MSRM average. This is due to the species composition adjustment and adjusting height and site index rather than height and age. The Boston Bar also yielded more volume (3.3 m^3/ha, 4%) than the MSRM standard adjustment procedure. We can therefore conclude that the MSRM adjustment procedures under-estimated volume in the Lignum IFPA area.

Table 19. Comparison between the Boston Bar and the MSRM adjustment protocols.

Adjustment protocol	Leading Species	Leading Species Height (m)	Leading Species Total Age (yrs)	Leading Species SI (m)	Net Merch Volume (m^3/ha)
Boston Bar	Pl	15.1	76	13.3	80.3
	Others	19.2	124	14.3	105.4
	Total	*17.2*	*101*	*14.3*	*93.4*
MSRM	Pl	15.5	86	12.5	84.8
	Others	19.1	112	12.5	94.5
	Total	*17.5*	*100*	*12.5*	*90.1*

After adjustment, the volume, basal area, QMD, number of tall fir trees, height, age, and site index were on average lower than the photo-interpretation estimates (Table 20), while stems/ha was higher (using the Boston Bar protocol). The unadjusted VRI database is biased and gives a distorted view of Lignum's inventory. The adjusted inventory database corrects this bias and therefore will provide Lignum with better information for managing their IFPA area.

Table 20. Comparison between initial estimate and adjusted estimate based on the Boston Bar protocol.

Attribute	Initial Estimate	Adjusted Estimate	Difference (%)
Live whole-stem volume – top & stump decay, waste, breakage			
4cm+ - All stands	141.1 m^3/ha	131.8 m^3/ha	-6.6
12.5cm+ - Pl leading stands	Unknown	80.3 m^3/ha	-
17.5cm+ - non-Pl leading stands	Unknown	105.4 m^3/ha	-
Lorey height	17.0 m	15.5 m	-8.8
Average breast-height age	104 yrs	101.1 yrs	-2.8
Site index	17.4 m	14.3 m	17.8
Basal area	22.5 m^2/ha	18.8 m^2/ha	-16.4
Stems/ha	846 tr/ha	1,201 tr/ha	42
Quadratic mean diameter	18.4 cm	14.1 cm	-23
Number of tall fir trees/ha	26 tr/ha	8 tr/ha	-69
Dollar value/ha	Unknown	$5,542/ha	-

VDYP version 6.6d did not estimate initial stand volumes accurately in the Lignum IFPA area, especially for Pl-leading stands, and should not be relied on. The alternative growth and yield models currently being developed by Lignum for their IFPA area should provide better management tools.

6. RECOMMENDATIONS

The Boston Bar statistical adjustment provides an unbiased VRI database for the Lignum IFPA area. Therefore, we recommend that

Lignum adopt the Boston Bar adjusted VRI database for operational purposes.

Sample plots in non-Pl leading stands tended to be in polygons with more attribute-adjusted volume than in the rest of the population. This could not be explained other than by chance. Therefore we recommend that

Lignum further investigates the sampling selection process to explain the large difference between the sample and the population attribute-adjusted volume in non-Pl leading stands.

VDYP version 6.6d did not provide accurate volume estimates, especially for Pl-leading stands. Lignum is currently developing new growth and yield models. We recommend that

Lignum pursue its current research and development efforts in growth and yield modelling.

APPENDIX I – LAYER RE-APPORTIONMENT EXAMPLE

To illustrate the re-apportioning of polygon-level attributes at the layer, we use as an example a polygon with the following unadjusted (that is, Estimation Phase) information:

Layer	Basal Area	Basal Area (%)	Spp.1	Pct.1	Spp.2	Pct.2	Spp.3	Pct.3	Ht.	Age
1	**10** m^2/ha	20%	Fdi	80%	Pl	20%			25 m	80 yrs
2	**40** m^2/ha	80%	Fdi	40%	Sx	30%	Pl	30%	15 m	40 yrs

In a first step, the proportion (weighted by basal area) of each layer for a species was calculated. In the example, this gives:

Spp.	Layer	Proportion	Formula
Fdi	1	**33%**	(80%x**10**)/(80%x**10**+40%x**40**)
	2	**67%**	(40%x**40**)/(80%x**10**+40%x**40**)
Pl	1	**14%**	(20%x**10**)/(20%x**10**+30%x**40**)
	2	**86%**	(30%x**40**)/ (20%x**10**+30%x**40**)
Sx	2	**100%**	(30%x**40**)/(0%x**10**+30%x**40**)

The adjusted species volume was then assigned to each species using the species proportion. If an adjusted volume belonged to a species not in the Estimation Phase polygon, that volume was added to the layer with the most unadjusted basal area. For new species added to the label, the proportion of that species was assumed to be the proportion of basal area for the entire layer. If the adjusted volumes for the example were Fdi 200 m^3/ha, Pl 100 m^3/ha, and Py 50 m^3/ha (with Sx missing), the adjusted volume for each species and layer was:

Spp.	Adjusted Polygon Volume	Layer	Proportion	Layer Volume
Fdi	200 m^3/ha	1	**33%**	**66.7** m^3/ha
		2	**67%**	133.3 m^3/ha
Pl	100 m^3/ha	1	**14%**	**14.3** m^3/ha
		2	**86%**	85.7 m^3/ha
Sx	0 m^3/ha	2	**100%**	0.0 m^3/ha
Py	50 m^3/ha	1	**20%**	**10.0** m^3/ha
		2	**80%**	40.0 m^3/ha

For Fdi, layer 1, 33% x 200 = 66.7 m^3/ha.
For Py, an unexpected species, the volume is split between layers based on the total basal area of each layer. So, for Py, layer 1, 20% x 50 = 10.0 m^3/ha.

The volumes can be re-organized by layer:

Layer	Spp.1	Volume 1	Spp.2	Volume 2	Spp.3	Volume 3	Spp.4	Volume 4
1	Fdi	**66.7** m^3/ha	Pl	**14.3** m^3/ha	Py	**10.0** m^3/ha	Sx	**0.0** m^3/ha
2	Fdi	133.3 m^3/ha	Pl	85.7 m^3/ha	Py	40.0 m^3/ha	Sx	0.0 m^3/ha

The adjusted species composition by layer can easily be recalculated from the adjusted species volume:

Layer	Spp.1	Pct.1	Spp.2	Pct.2	Spp.3	Pct.3
1	Fdi	73%	Pl	16%	Py	11%
2	Fdi	52%	Pl	33%	Py	15%

For Fdi, layer 1, **66.7** / (**66.7**+**14.3**+**10.0**+**0.0**) = 73%.

In the next step, layer proportion is calculated from the adjusted species volume by layer. In this example, the total volume for the polygon is 350 m^3/ha, the first layer has an adjusted volume of 91 m^3/ha (81=66.7+14.3+10.0, 91/350=26%), and the second layer has 259 m^3/ha (133.3+85.7+40.0, 259/350=74%). Volume, dollar value, basal area, and stems/ha were assigned based on these proportions. For instance, in the example, the first layer would be assigned 26% of all volumes and the second layer would be assigned 74%. Number of tall fir/ha was assigned to the tallest layer (layer 1). In the example, if the adjusted number of tall fir/ha was 30, the first layer would be assigned all 30 tall fir trees.

For all heights and ages, weighted average estimated height and age were first calculated using unadjusted species composition and height (or age). In the example, the weighted average estimated height would be 17 m (=20% x 25m + 80% x 15 m), and the weighted average estimated age would be 48 years. For each height and age, a ratio between the adjusted attribute and the corresponding average was calculated. For instance in the example, if the adjusted total age was 55 years, the total age correction ratio would be 1.146 (= 55yrs/48yrs). The adjusted total age by layer would then be 91.7 years for Layer 1 (=80yrs x 55/48) and 45.8 years for Layer 2 (=40yrs x 55/48).

APPENDIX II – BOSTON BAR ADJUSTMENT – LIVE VOLUMES

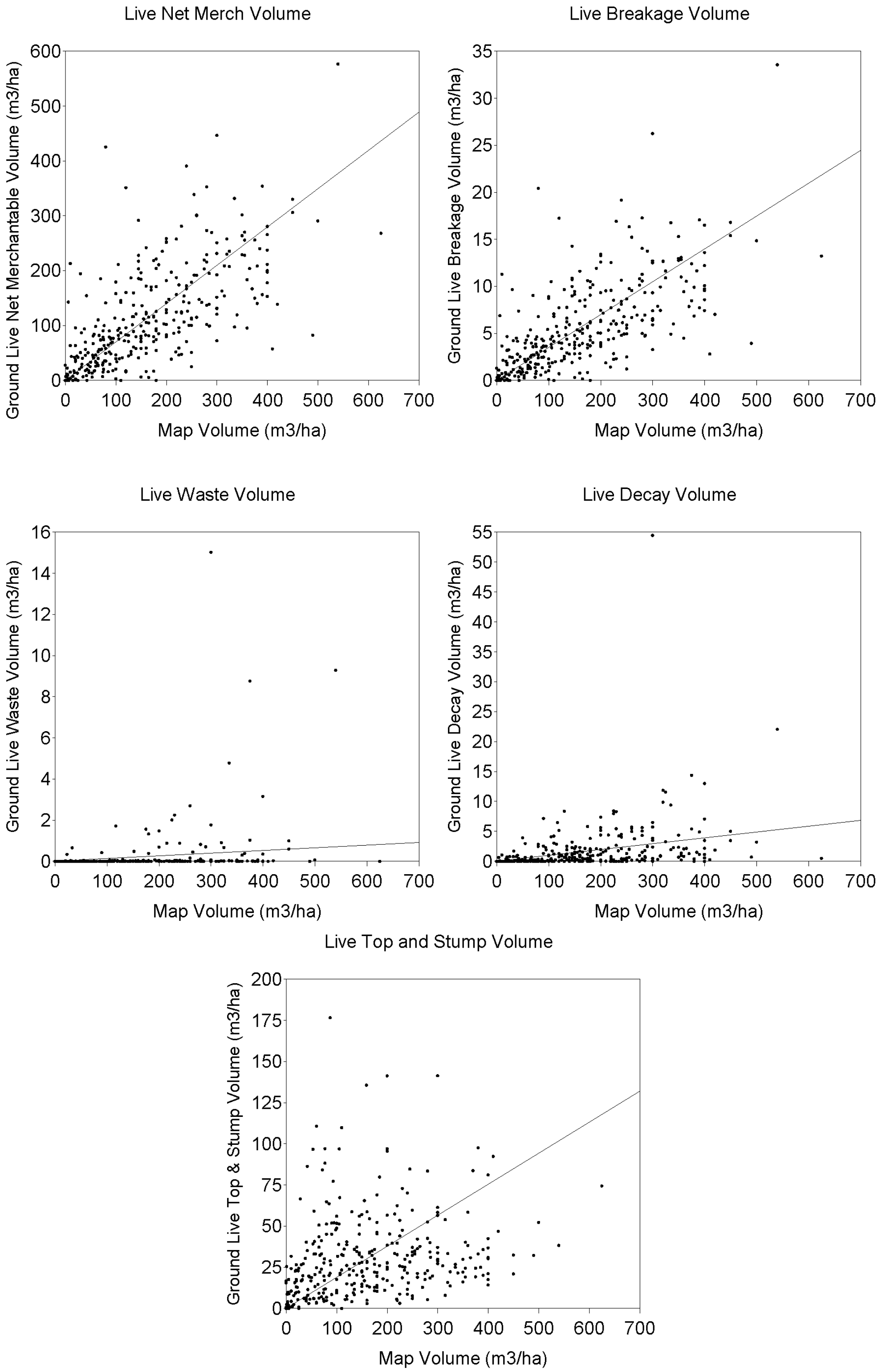


Figure 10. Ground live volumes vs. map live volumes.

APPENDIX III – BOSTON BAR ADJUSTMENT – SPECIES VOLUME

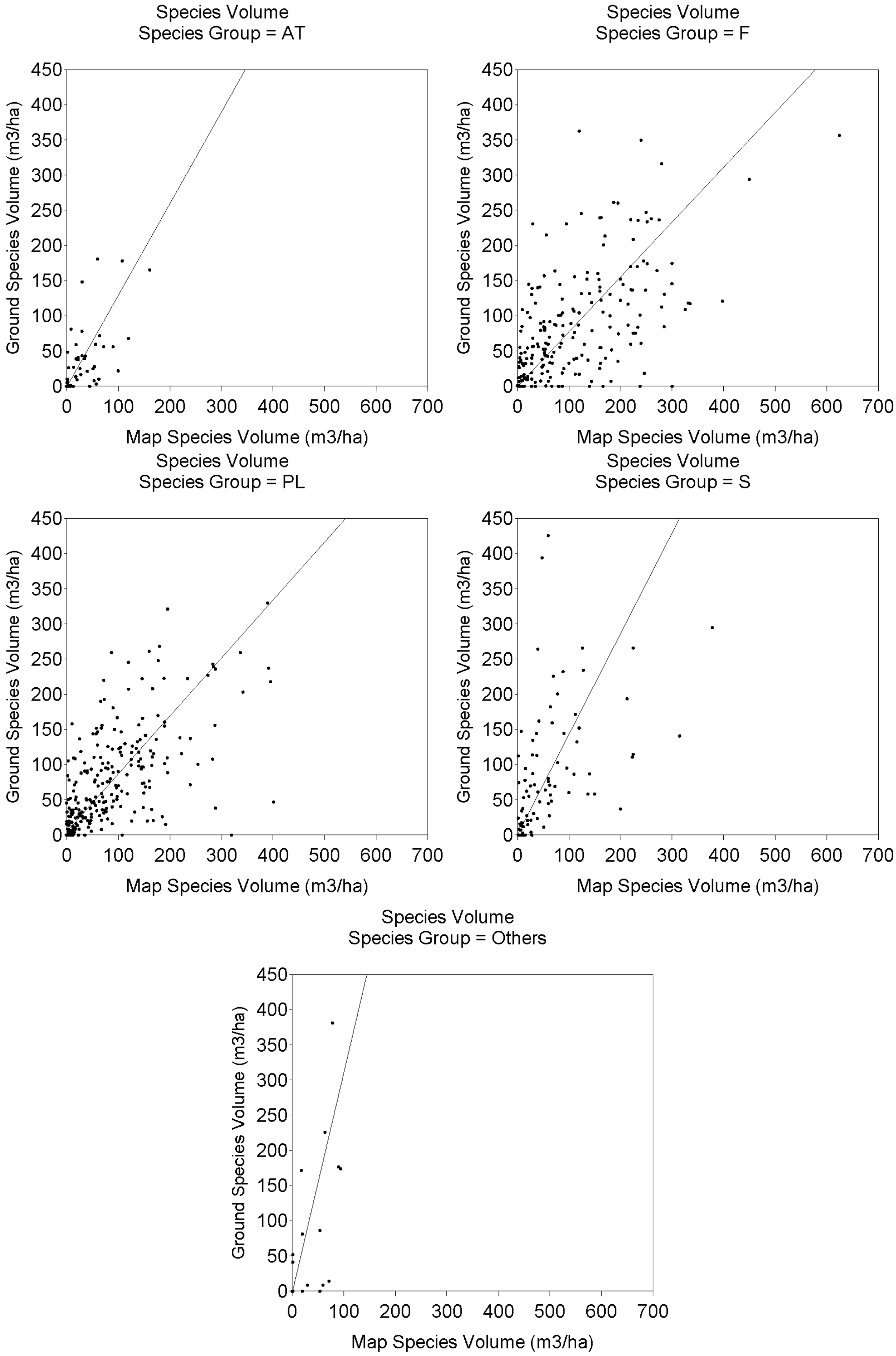


Figure 11. Ground species volume vs. map species volume.

APPENDIX IV – BOSTON BAR ADJUSTMENT – DEAD VOLUMES

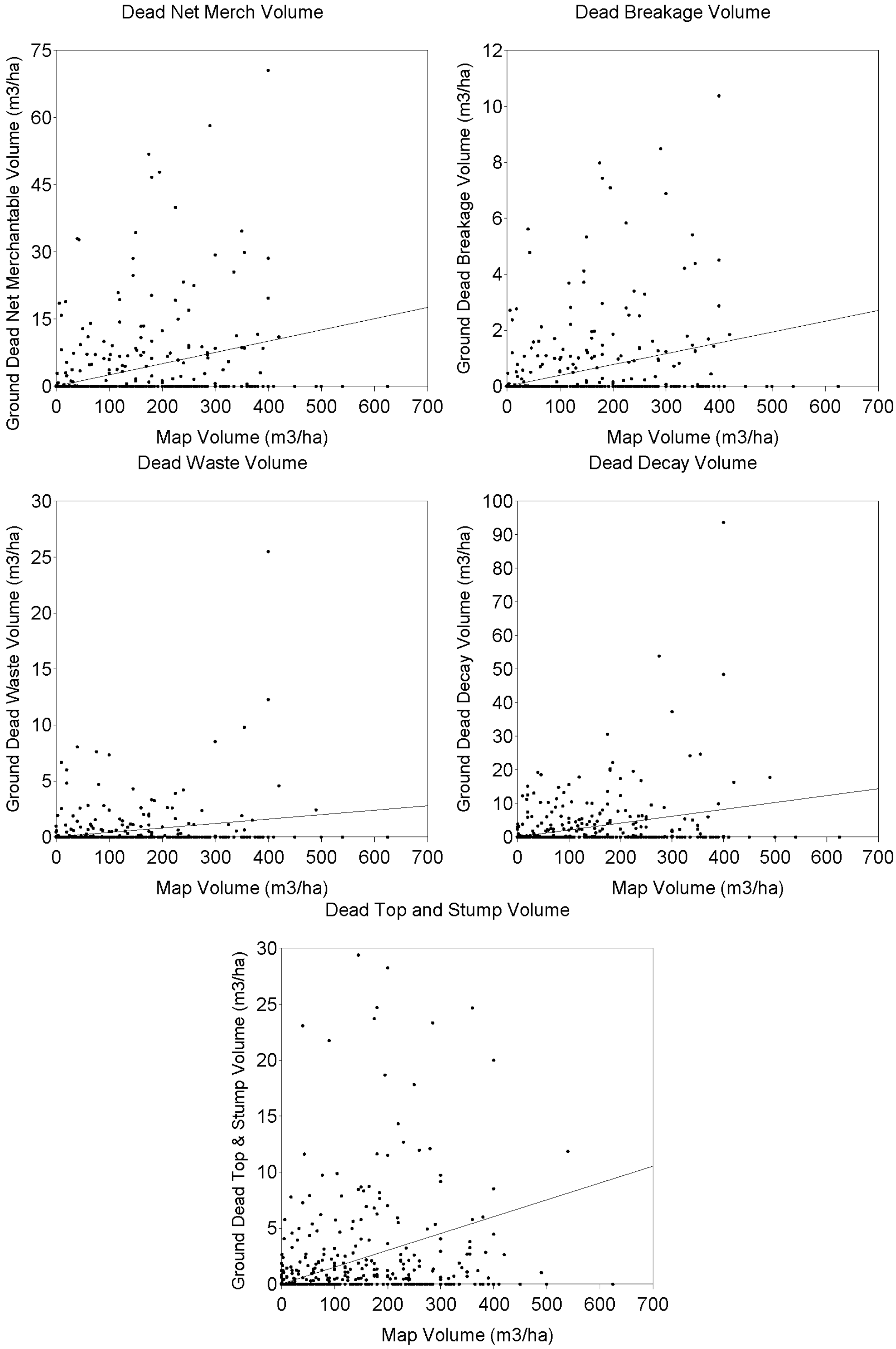


Figure 12. Ground dead volumes vs. map dead volumes.

APPENDIX V – BOSTON BAR ADJUSTMENT – LOREY HEIGHT AND BREAST-HEIGHT AGE

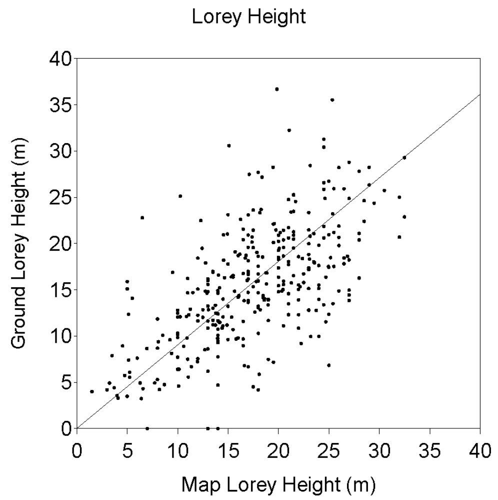


Figure 13. Ground Lorey height vs. map Lorey height.

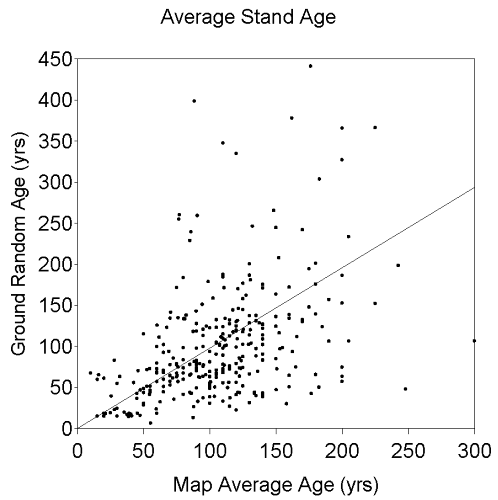


Figure 14. Ground random age vs. map average age.

APPENDIX VI – BOSTON BAR ADJUSTMENT – HEIGHT AND SITE INDEX

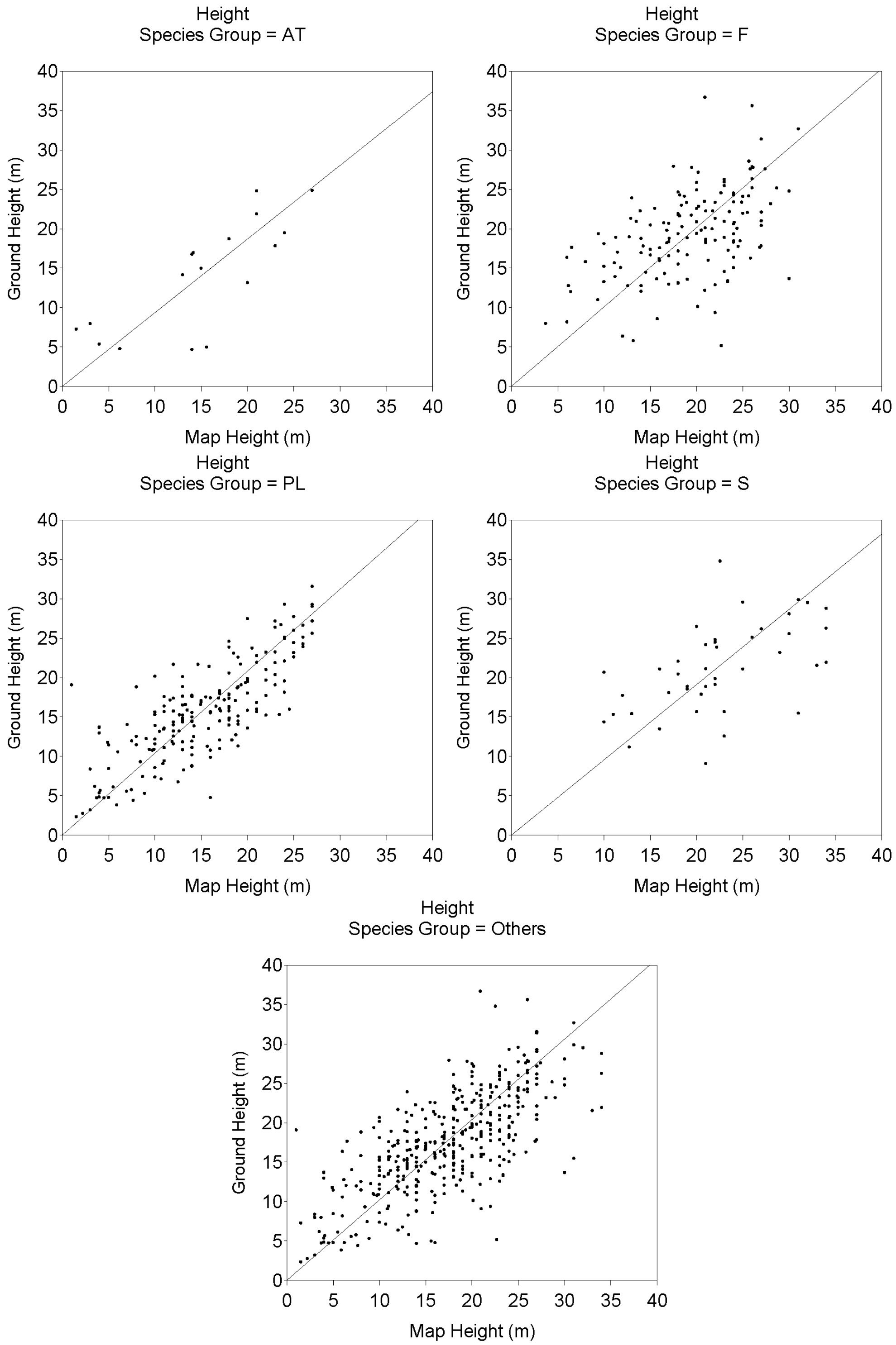


Figure 15. Ground species height vs. map height.

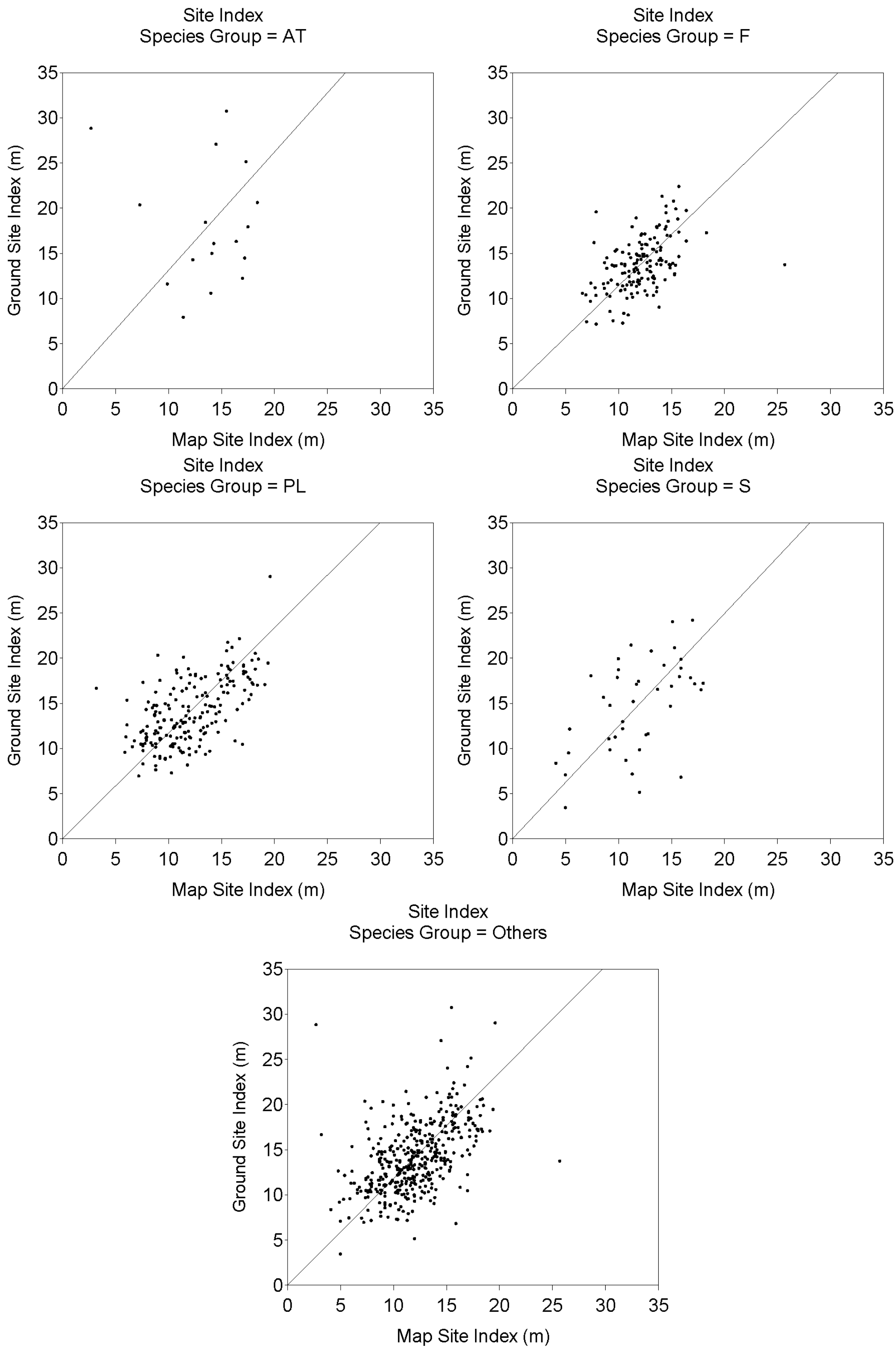


Figure 16. Ground site index vs. map site index.

APPENDIX VII – BOSTON BAR ADJUSTMENT – BASAL AREA, STEMS/HA, TALL FIR TREES/HA

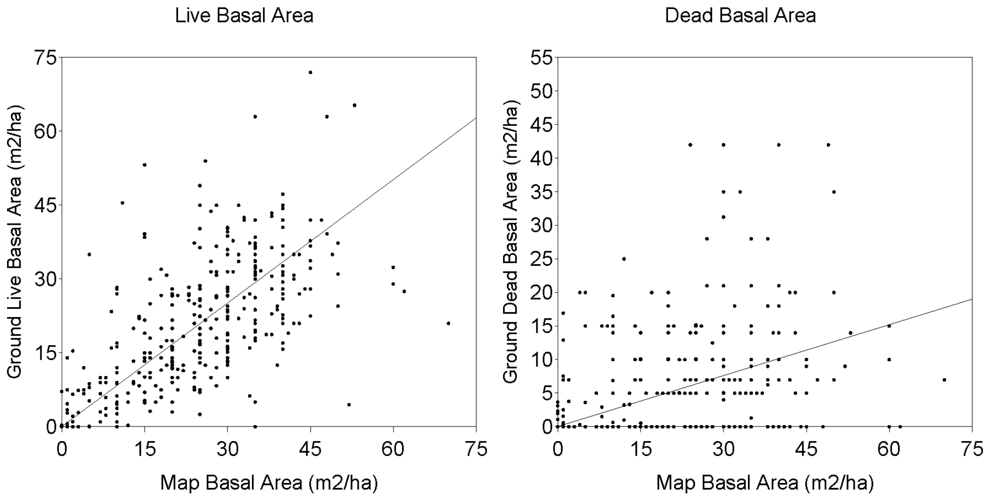


Figure 17. Ground basal area vs. map basal area.

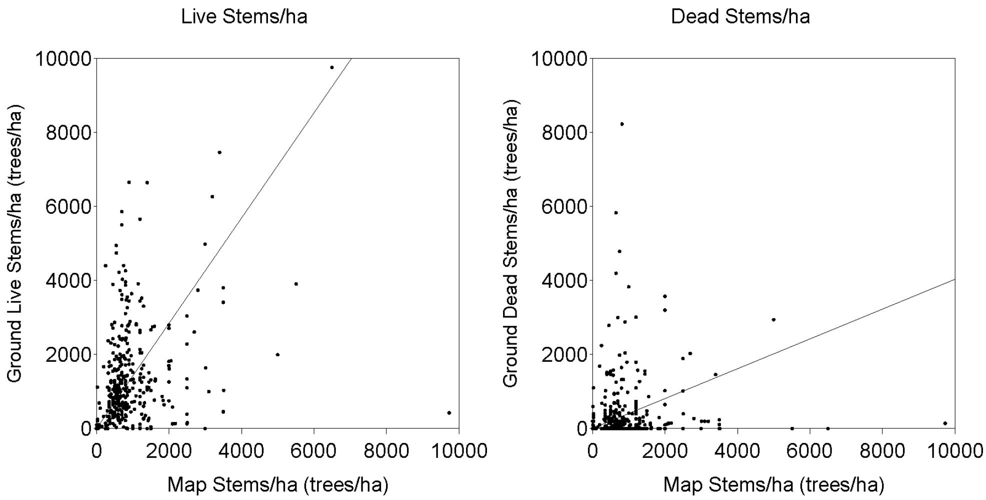


Figure 18. Ground stems/ha versus map stems/ha.

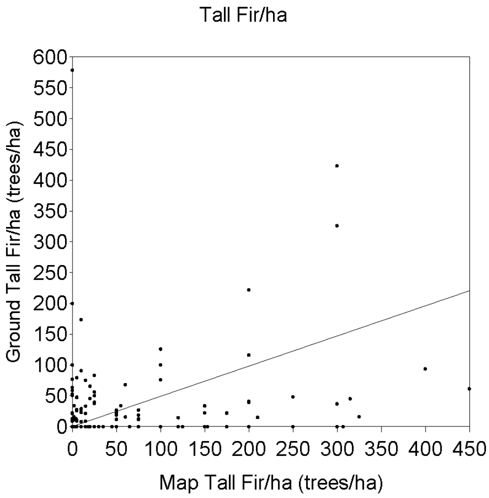


Figure 19. Ground tall fir trees/ha vs. map tall fir trees/ha.

APPENDIX VIII – BOSTON BAR ADJUSTMENT – DOLLAR VALUE/HA

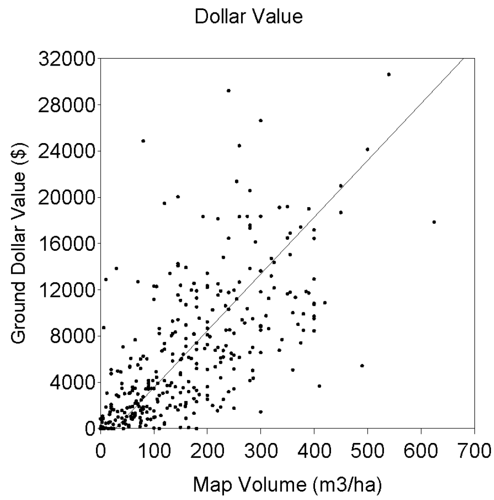


Figure 20. Ground dollar value/ha vs. map volume.

APPENDIX IX – MSRM ADJUSTMENT

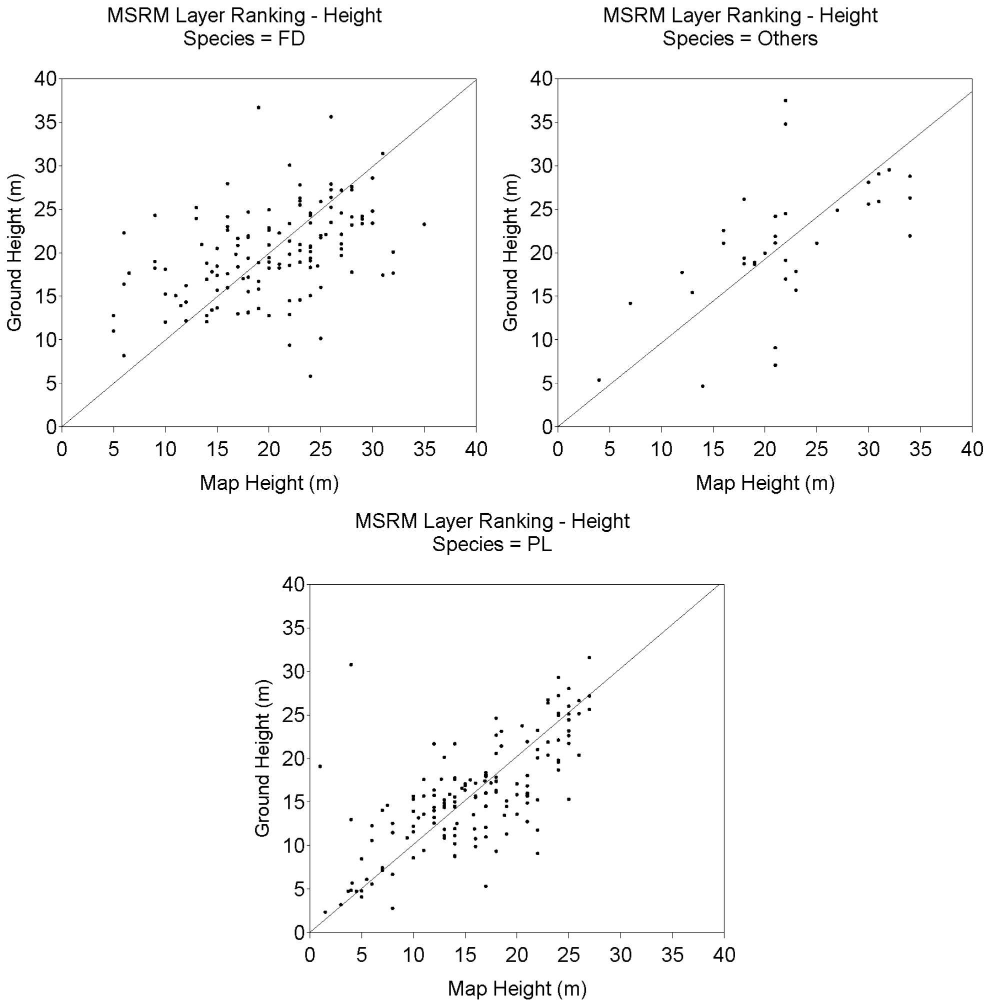


Figure 21. Ground height vs. map height (MSRM adjustment).

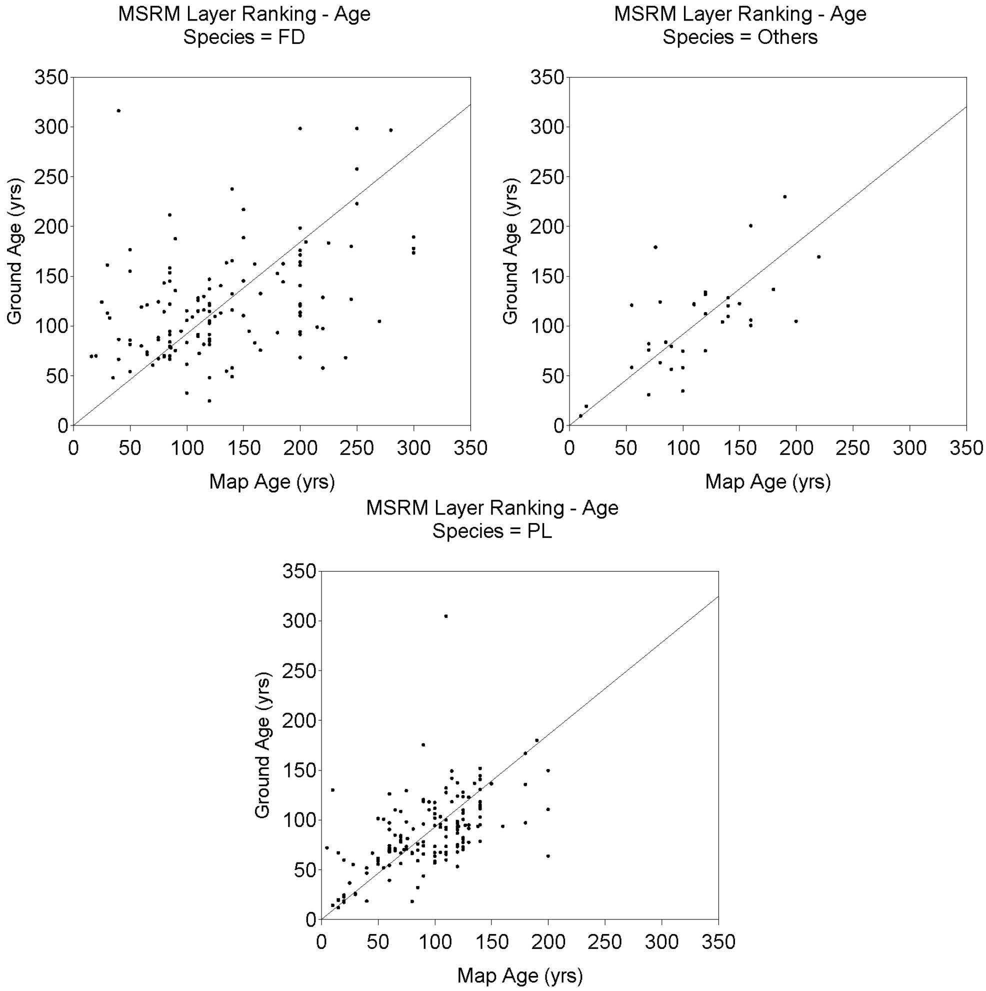


Figure 22. Ground age vs. map age (MSRM adjustment).

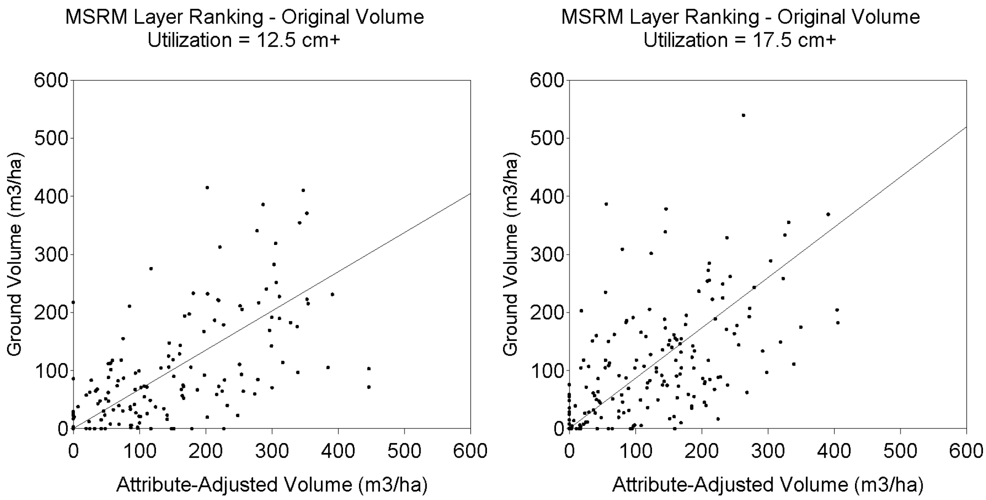


Figure 23. Ground volume vs. attribute adjusted volume (MSRM adjustment).