

Volume to Biomass Conversion

For

British Columbia Forests



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DRAFT

By

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Executive Summary

The objective of this project is to attach biomass estimates to each VRI polygon in the provincial Vegetation Resources Inventory (VRI) Management System database. This project is a collaborative effort between the Canadian Forest Service (CFS) and the British Columbia Ministry of Forest and Range (MFR). The CFS completed a similar project a few years ago, and the MFR has leveraged that effort to develop volume-to-biomass conversion equations for British Columbia. This project deals with aboveground live tree biomass.

First, temporary and permanent sample plot data from various sources were assembled. Missing tree heights were estimated and bole, bark, branch and foliage biomass was estimated for each tree. The biomass equations and compilation routines were adapted from the CFS procedures.

Next, the plot-level data were used to develop stand-level volume-to-biomass conversion factors. The main conversion factors convert volume at the 4.0 utilization level to biomass components (bole, bark, branch and foliage) at the $Dbh \geq 4.0\text{cm}$ utilization level. The choice of utilization level was a compromise between including as much of the above ground biomass as possible and including as much plot data as possible (many of the plots did not measure trees with $Dbh < 4.0\text{cm}$). Additional conversion factors were estimated to convert volume at 7.5, 12.5, 17.5 and 22.5 cm utilization levels to biomass at the same utilization level. Ratios to convert biomass at the 4.0cm utilization level to biomass at 2.0, 7.5, 12.5, 17.5 and 22.5 utilization were also estimated. In general, the conversion factors are by species group and BEC zone. If sufficient data were not available, conversion factors were estimated by species group, for all BEC zones combined.

The results of the analysis show strong relationships between calculated bole (wood), branch, bark and foliage biomass values and ground-measured stand whole-stem volume by species at the plot level.

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After producing a preliminary report, Dave Morgan, Manager of the biometrics unit at the Alberta Sustainable Resource Development Ministry, and Caren Dymond at the Ministry of Forests and Range provided valuable advice on improving the draft.

It is the contribution of these professionals that made the completion of this project possible.

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INTRODUCTION & BACKGROUND

Nationally and internationally there is increasing interest in assessing carbon-budgets due to climate change, i.e., carbon uptake and release. British Columbia has a stake in this assessment, given its large forested land base.

Biomass and carbon information is required to feed into carbon models, to assess changes in sequestration over time, and to evaluate the availability of bio-energy resources.

Objectives

The objective of this project is to attach biomass estimates to each Vegetation Resources Inventory (VRI) polygon in the provincial VRI Management System database. This report is part of an initiative that will provide biomass information at a polygon level for the British Columbia forest inventory. Biomass includes over-story (tree) biomass, understory vegetation biomass, wood debris mass and soil organic matter biomass.

Definition of Biomass

Biomass is the over-dried weight (Kilograms or tonnes per hectare) of organic matter that can be found in ecosystem at any given time (Penner et al, 1997). This includes both live and dead vegetation material. In a forestry context biomass material includes the following:

1. Above ground live tree biomass
 - a. Tree stem or bole wood
 - b. Tree branches
 - c. Tree bark
 - d. Tree foliage
 - e. Fruit and flowers (these are ignored)
2. Below ground live tree biomass
 - a. Tree roots
 - b. Germinating seeds
 - c. Rhizome stems
 - d. Rhizome roots
3. Above ground dead material
 - a. Dead standing tree stems
 - b. Dead fallen tree stems
 - c. Dead tree branches
 - d. Coarse woody debris in various states of decay
4. Other vegetation cover
 - a. Small live trees with their foliage
 - b. Herbs and shrubs
 - c. Bryoids and grasses
 - d. Moss & lichen
 - e. Fungi
5. Soil organic matter

- a. Decaying foliage
- b. Other humus material

This report only deals with above ground live tree biomass (biomass category 1, above). The other categories will be considered later because suitable data to estimate them credibly is sparse at the moment, and estimation techniques are not well developed.

METHODS

Developing and calibrating models to estimate tree biomass from tree measurements such as Dbh and height is both time-consuming and expensive. Typically, the procedure involves selecting sample trees randomly or by some systematic process. The sample trees are then destructively sampled such that loss of material (e.g., leaves, fine branches) is minimized. The branches are removed from the tree and then separated into branch wood and foliage. The bark may be peeled off both the branches and the tree bole. The fresh weights are generally measured in the field and samples are taken of the different components. These samples are taken to a lab and oven-dried to obtain fresh weight to oven dry weight conversion factors. The work is tedious, labour intensive, and costly.

Below is a description of biomass data collection in Alberta by Dave Morgan¹

“The approach we used was to measure tree DBH and total height. Cookies were cut from the tree following our normal tree section methodology. Samples of different size classes of branches were selected, weighed green (leaf on) and then after oven drying. The cookies were weighed and measured in 2 directions including the one from DBH. The sizes of the cookies were then adjusted for shrinkage based on the ratio of the cookie at DBH. The difference was <10%. The leaves and the tree bark either fell off or could easily be removed following drying but prior to weighing.”

The approach taken here is to use existing regional and national tree biomass equations and make use of work done to develop convert stem volume to biomass components.

Lambert et al. (2005) and Ung et al. (2008) produced national tree biomass equations and Standish et al. (1985) produced estimates for BC. These equations were used by Boudewyn et al. (2007) to develop equations to convert stand or polygon volumes to biomass. The equations were used here to predict biomass from tree Dbh and height. Then the individual tree volume and biomass estimates were used to develop equations to convert volume to biomass. This was done for two reasons a) the intent was to leverage a process already developed by the CFS to estimate tree biomass, and b) there are application restrictions on the individual tree biomass equations that would be difficult to resolve for BC conditions.

In applying Ung et al.’s (2008) equations, we were aware that in some cases we were applying the equations beyond the range of data. Ung, et al states; *“Descriptive statistics per species given in Table 2 (reproduced here as Appendix E) provide domain bounds beyond which the application of the empirical allometric equations is not recommended”*. As an example from the table, the Douglas fir

¹ Dave Morgan, Manager, Forest Biometrics Unit, Sustainable Resource Development, Alberta, Canada (2010). Personal communication

equations should not be used for trees bigger than 50.8cm in the coastal region. Douglas fir on the coast grows to much larger DBHs than 50cm. Generally volume equations have been developed from larger datasets with a wider range in tree size than the biomass equations. For this reason, it was felt that first predicting stem volume from Dbh and Ht and then converting that to biomass would lead to better results than predicting biomass directly from Dbh and Ht. In addition, a wood density check was conducted to detect potential extrapolation problems.

Wood density data from Gonzalez (1990) was used to check the reasonableness of the calculated tree biomass. For instance, the Gonzalez report lists the minimum and maximum density of wood biomass for Douglas fir as 323 Kg/m³ and 615 Kg/ m³, respectively. If a Douglas fir (Fd) tree with known volume produced a biomass that resulted in a density higher than 615, we reviewed and checked the biomass for that tree to determine if it was reasonable.

The SAS code the CFS used to analyse the national data was reviewed and modified to suit BC requirements. A small dataset consisting of sample trees selected from all the available BC data set was assembled to fine-tune the CFS software.

The first step in the process was to assemble all the tree data.

The second step was to estimate heights for trees missing that attribute.

The third step was to estimate tree bole, branch, bark and foliage biomass for each tree.

Finally, ratios were computed to predict biomass components as a function of stem volume.

Step 1- Data assembly

The first step in the process was to assemble all the tree data from the Vegetation Resources Inventory (VRI), the National Forest Inventory (NFI), the Change Monitoring Inventory (CMI), the inventory audit (Audit), the temporary sample plots (TSP), and the permanent sample plots (PSP) together into one file. Data assembly was complicated by the requirement to attach eco-zone and BEC² zone to each tree. Eco-zones were derived from BEC, BEC sub-zones & BEC variants.

Each data source had its own lower Dbh limit. The TSP data were collected between 1950 and 1983 and is the most complete dataset in terms of coverage of different environmental conditions. The audit dataset came from random locations; however, the data collection was initially restricted to stands 60 years in age or older. Later, data were collected from younger stands as well, but the data were difficult to retrieve as they were not archived in the same way as the earlier data.

² BEC stands for Bio-geo-climatic Ecosystem Classification system which was originally developed for BC by Dr. V.J. Krajina.

Table 1. BC sample types, minimum tagging limits and age range for data collection.

Source	Number of plots	Minimum Dbh tagging limit	Age classes sampled
PSPs	9,000	2.0cm	0 yrs+
TSPs	>50,000	7.5cm	Mostly 40yrs+
VRI/CMI	7,000	4.0 cm	CMI- 15-40yrs VRI – 30yrs +
NFI	268	9.0 cm	0 yrs+
Audit	3,500	12.5 (Interior) 17.5 (Coastal)	60 yrs+

Step 2 - Height prediction

During the development of VDYP7 – an MFR height diameter model technical committee (Bartram, 1997) produced a set of height/ DBH functions to predict heights for permanent sample plots (PSPs). Extraction and use of that software was not feasible. This project developed a simpler equation provided below:

(eqn. 1)
$$Ln(Ht) = b_0 + b_1 * Ln(Ba)$$

Where: $Ln(Ht)$ = natural log of tree height
 $Ln(Ba)$ = natural log of tree basal area
 b_0 and b_1 = least squares regression coefficients

This relationship has a number of interesting characteristics, such as:

- a) The regression line has one known point through which we expect the prediction line to pass. That point is when tree basal area is 1.0cm² and tree height is 1.3m. At that point the natural logs of height and basal area are; 0.262364 and 0.0 respectively. (???)
- b) For most of the tree species in British Columbia, the relationship is linear (see Figure 1)
- c) The conversion of $Ln(Ht)$ back to height in meters is simple – $Ht = Exp(Ln(Ht))$.
- d) The known point on the regression line can be exploited to make tree height data collection more efficient. Only two points are needed to define a straight line. In this scenario, the 1.3m height would define the lower end, and the tallest trees in the population would define the upper end of the line. The implication is that tree height measurement effort would best be invested in measuring heights of the tallest trees at the upper end of a straight prediction line for a given population of trees.

Estimation of the height of broken top trees is very difficult. Heights of all broken top trees should be measured in the field to avoid having to estimate height.

Equation 1 can be written as a function of Dbh:

$$Ht = b_0 \cdot BA^{b_1} = b_0 \cdot (Dbh^2 \cdot \pi / 2)^{b_1} = b_0 \cdot (\pi / 2)^{b_1} \cdot (Dbh)^{2b_1}$$

$$Ht = b'_0 \cdot Dbh^{b'_1}$$

(eqn. 2)

where

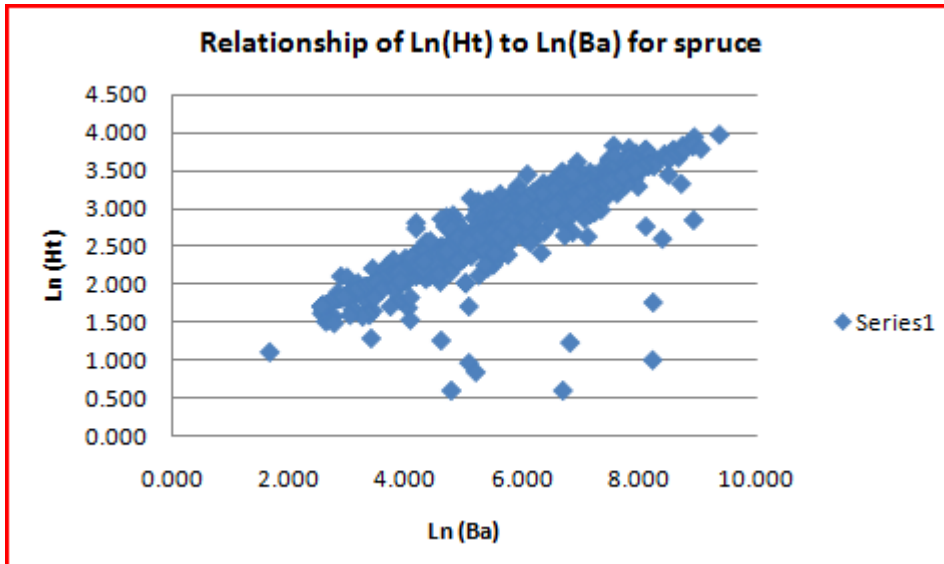
$$b'_0 = b_0 \cdot (\pi / 2)^{b_1}$$

$$b'_1 = b_1 / 2$$

A variation to Equation 2 was implemented by the height diameter model technical committee (Bartram 1997). We preferred to use the linear form because it was easier to identify broken top trees.

In the current implementation of Equation 1, no modification was applied to correct for potential bias arising from using logarithms rather than the actual measured height and DBH. Baskerville (1971), Wiant and Harner (1979) and Hayes and Shonkwiler (2006) have discussed the estimation bias. We believe the bias is too small relative to other sources of error and variation in biomass estimation. For instance, the r^2 for the Standish et al. (1985) foliage biomass prediction equations ranged from 0.02 to 0.71 for the simple linear model. The next iteration of the biomass estimation will correct for the log transformation bias.

Figure 1. Typical relationship³ between the natural log of height and the natural log of basal area.



Step 3 – Prediction of tree Biomass components

The computed tree biomass data are expressed in tonnes per hectare. Above-ground biomass can be broken down into four components: bole, branch, bark and foliage. The bole biomass is usually the largest because most of the wood of a tree is in the bole (or trunk). Branch biomass ranks next in terms

³ The “outlier” values are for broken top trees.

of quantity. Bark and foliage biomass tend to rank 3rd and 4th, respectively. Initially the intent was to derive only volume-to-total biomass conversion factors. However, we realised that biomass information users may wish to exclude some components of biomass in their analysis of resource availability. For instance, a bio-energy plant may be interested in utilizing bole and branch biomass, but not in foliage or bark biomass. Therefore we derived separate estimates for the four components of above-ground tree biomass.

Volume and biomass in the database were expressed as per hectare values using a conversion factor that created per hectare values out of area-based attributes at the tree level. Each tree had its own per hectare factor depending on its diameter or plot size⁴

Most of the trees in the file had taper equation-based, whole-stem volumes attached to them from past compilations. Those trees carried their volumes into the new file. Some trees from the old inventory audit era did not have associated tree volumes. The MFR taper function tool (TreeVol) was used to generate volumes for each of them.

The wood density, calculated as $Density = Biomass / Volume$, was compared to the Gonzalez (1990) density-table values. If the computed density was outside the published range, the average published value was used and the biomass values recalculated.

Step 4 - Fitting Stand-level Biomass prediction functions

Each dataset had its own utilization standard⁵ (0) so the choice of utilization standard for biomass conversion affects which datasets are included. Our preference would have been to use the 2.0cm utilization for the volume-to-biomass conversion project. This would have ensured the inclusion of smaller trees for which estimation of biomass is difficult. Unfortunately, only a few datasets have tree data measured to a 2.0cm minimum Dbh, too few to allow construction of reliable volume-to-biomass relationships. Also, VDYP7 cannot generate volumes for the 2.0cm utilization level, so there was no corresponding VRI volume to be converted to biomass.

VDYP7 is calibrated based on the 7.5cm utilization level, so it would have been ideal to work with that utilization level. However, that choice would have required the exclusion of a significant component of the inventory, i.e., trees with Dbhs between 4.0cm and 7.5cm. This would have resulted in underestimation of biomass, and additional steps would have been required to take those trees into account.

The current analysis is based on the 4.0cm Dbh minimum level. This worked well because there were many MFR samples measured to this utilization level (or tagging limit). For instance, all VRI ground samples are measured to a minimum Dbh of 4.0cm, and a considerable number of PSPs were measured to this diameter limit. This limit allowed us to include small trees which are usually troublesome to analyse. Thus we were able to estimate above-ground biomass for all situations where there are trees larger than 4.0cm in diameter in a single step.

⁴ With a fixed-area plot every tree has the same expansion factor based on plot size.

⁵ The expression “tagging limit” rather than a utilization limit is used in most of the other provinces in Canada, but in BC, utilization standard is used more frequently.

The process used to create tree-level biomass for the BC sample trees was similar to that used by the Boudewyn et al. (2007) with a few minor exceptions. New height-diameter functions were used to attach heights to trees that did not have them, and published tree species wood density information was used to modify unrealistic biomass estimates.

At the stand level, the CFS used a two-step process to convert volume to biomass. In the first step, functions were developed to estimate the biomass of merchantable trees, the biomass of unmerchantable trees as a function of the biomass of merchantable trees and the biomass of saplings as a function of the biomass of merchantable and un-merchantable trees. In the second step, the proportions of the different components of biomass were fitted against net merchantable volume per hectare. In both the first and the second steps, the functions developed were non-linear.

The MFR used a different approach. The biomass for the different components, i.e., bole, branch, bark and foliage, were fitted directly against whole-stem volume at the 4.0cm Dbh utilization level. The relationship between biomass and whole stem volume was assumed to be linear for all four components with an expectation of a zero intercept.

In situations where a relationship between two attributes is linear and the intercept is expected to be zero, there are two options for developing estimation functions. The first option is to compute ratios of means for the attributes and strata of interest. This option is efficient because ratios are easy to compute, and is appropriate when the variance of Y increases with X.

The second option is to fit least-squares regressions with a zero intercept to the data. This option is appropriate when the variance of Y for a given X is constant. This option was chosen because it gave a better understanding of the relationship between biomass and volume.

The general form of the volume-to-biomass conversion equation was:

(eqn. 3)
$$Biomass_{ij} = b_{ij} \cdot Volume_i$$

Where: *Volume_i is whole stem volume m³/ ha at the 4.0 cm utilization level - the same volume used for all four Biomass components (j), i.e., the predictor variable was the same but the dependent variable changed depending on the biomass component.*

b_{ij}= Least squares regression coefficient (slope) for biomass component j (j=1 - .4, where: 1=bole, 2=branch, 3=bark & 4=foliage).

Generally, the magnitude of the slope (*b_{ij}*) coefficient for a given biomass component reflects the proportion of that component in relation to the other three components for a given Sp0, within a BEC zone.

The volume-to-biomass factors used in this analysis were created by BEC and genus (SP0). Below are two examples of the scatter-plots of the biomass and the whole stem volume for Lodgepole pine (Pl) and Cottonwood (Ac).

Figure 2. Whole stem volume (per hectare) relationships with bole and branch biomass (per hectare) for Cottonwood species in the BWBS BEC zone.

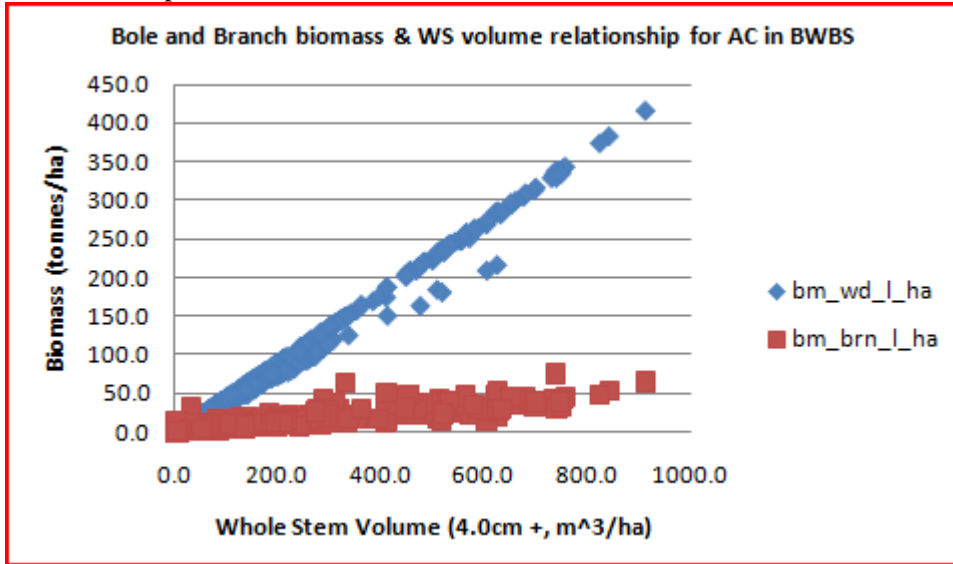
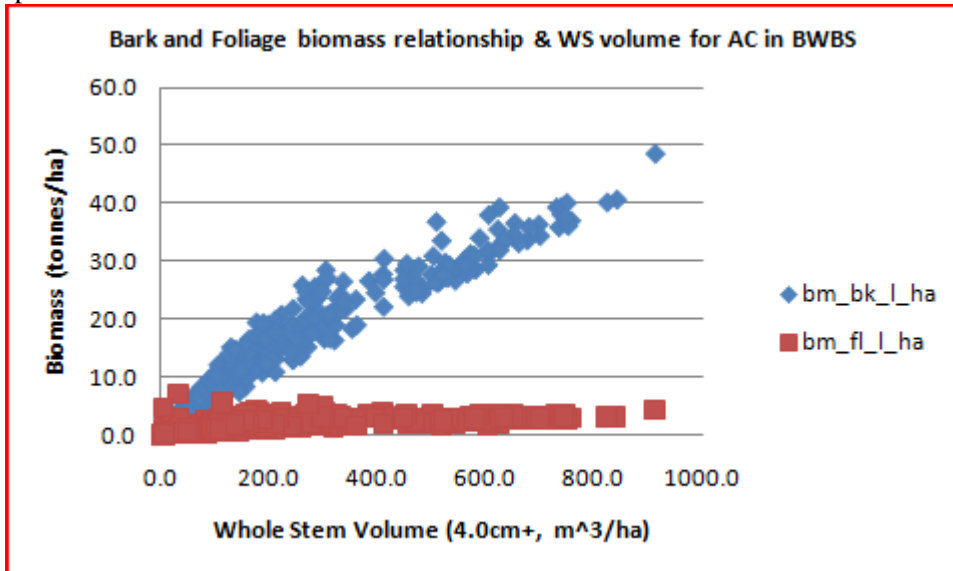


Figure 3. Whole stem volume (per ha) relationships with bark and foliage biomass (per ha) for cottonwood species in the BWBS BEC zone.



RESULTS

Data Summary

The tree-level information was summarised into several hierarchical levels. At the lowest level, data were summarized by sample plot, BEC zone (Figure 4) and genus (SP0 – 1). At a higher level, the data was summarized by BEC and genus (SP0). The frequency of sample trees by BEC/Sp0 strata is provided in Table 3.

Table 2. The species associated with the 16 sp0 codes are given.

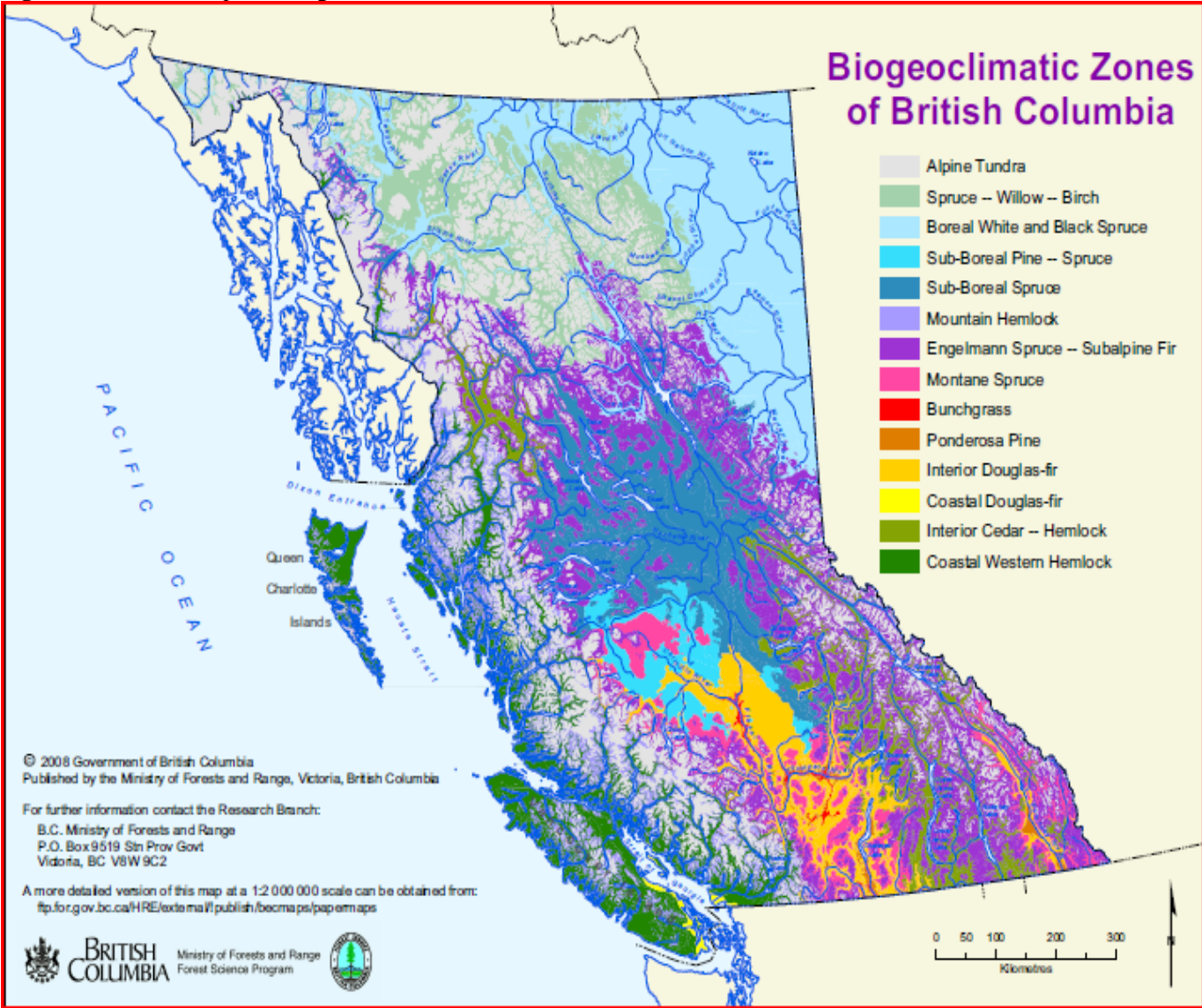
Sp0	Genus	Species codes	Interpretation
AC	A	Anything but AT starting with 'A'	Cottonwood
AT	A	AT	Aspen
B	B	Anything starting with 'B'	Balsam (abies)
C	C	Anything starting with 'C' (except 'CP' or 'CY'), 'I', or 'J'	Cedar (excluding yellow cedar)
D	D	XH, anything starting with 'D', 'V', or 'W'	Alder
E	E	Anything starting with 'E'	Birch
F	F	XC, anything starting with 'F'	Douglas-fir
H	H	TW, anything starting with 'H'	Hemlock
L	L	Anything starting with 'L'	Larch
MB	M	GP, QG, RA, anything starting with 'K', or 'M'	Maple
PA	P	PA, PF	White-bark pine
PL	P	Anything but PA, PF, PS, PW, or PY starting with 'P'	Lodgepole pine, and jack pine
PW	P	PS, PW	White pine
PY	P	PY	Yellow pine (Ponderosa pine)
S	S	Anything starting with 'S'	Spruce
Y	Y	CP, CY, anything starting with 'Y'	Yellow cedar
blank	blank	Everything else	invalid code

Table 3. The frequency of the tree samples by BEC and Sp0 is given.

Sp0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	2		1717	2	324	121	762	105	4	47	2	37	1017	58
AT	4	1	3168		95	404	2053	1515		416	16	479	4163	188
B	219		714	56	5585	8245	4697	353	537	1534	1	98	6619	595
C	1			94	7677	906	6492	447	87	171	2	2	185	
D			110	61	1999	92	226	40	2	51		7	254	
E	2		1679	30	889	156	3120	918	1	208	4	57	2881	31
F	10	10	14	169	4225	1408	5215	4844	56	1347	248	226	2220	
H	23			83	10456	1604	5921	120	557	62			466	
L	9		211		7	441	2411	594	3	468	4		3	4
MB				48	544	8	280	164		17			24	
PA	52				23	544	13	6		43			6	
PL	54		2867	42	1184	3785	3297	3485	9	2754	12	1342	7397	690
PW	5			7	882	399	2786	83	37	59	1			
PY					3	9	143	954		38	250	769	3	
S	183		4472	8	3317	7861	5479	1515	73	2005	3		9109	1025
Y	3	3		1	1848	21		1	197					

The BEC zone effect on differences in biomass was considered to be significant so, where possible, estimates were derived by sp0 and BEC zone.

Figure 4. A map of Bio-geo-climatic zones in British Columbia.



A summary of the data by BEC zone and Sp0 is provided in Appendix B.

Volume to Biomass Conversion Factors

Four tables of regression coefficients were generated; one for each component of biomass, i.e., bole, branch, bark and foliage. The bole biomass coefficients are provided in Table 4. The coefficients for the branch, bark and foliage biomass are provided in Table 11, Table 12, Table 13 (Appendix C), respectively.

Table 4. Regression Coefficients for bole (wood) biomass fitted by regression without intercept for BEC and genus (Sp0)

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	0.5351	0.4803 ⁶	0.4378	0.3287	0.4840	0.5412	0.5295	0.4656	0.5016	0.4845	0.4652	0.4805	0.5308	0.4599
AT	0.4559	0.4165	0.3988	0.4411	0.4327	0.4631	0.4389	0.4549	0.4411	0.4377	0.4645	0.4544	0.4541	0.4214
B	0.4024	0.3752	0.3611	0.3229	0.3803	0.3882	0.3937	0.3636	0.3916	0.3780	0.3507	0.3855	0.3856	0.3741
C	0.2265	0.3001	0.3001	0.2662	0.3173	0.3028	0.3233	0.2867	0.3073	0.2713	0.4501	0.2661	0.2836	0.3001
D	0.4408	0.4408	0.4197	0.4360	0.4534	0.3975	0.4753	0.4239	0.4962	0.4281	0.4408	0.4712	0.4069	0.4408
E	0.5978	0.5506	0.5351	0.5989	0.5188	0.5755	0.5216	0.5231	0.5448	0.5412	0.4923	0.5249	0.5482	0.6358
F	0.3785	0.4066	0.4830	0.4812	0.5135	0.3804	0.3585	0.3699	0.5460	0.3820	0.4032	0.3860	0.3645	0.4195
H	0.4717	0.4300	0.4300	0.3901	0.4052	0.4310	0.4302	0.4193	0.4792	0.4262	0.4300	0.4300	0.4172	0.4300
L	0.4407	0.4730	0.4342	0.4730	0.5278	0.4677	0.4406	0.4689	0.4730	0.4738	0.5000	0.4730	0.4782	0.4983
MB	0.4900	0.4900	0.4900	0.4299	0.5187	0.4328	0.5849	0.5237	0.4900	0.5032	0.4900	0.4900	0.4371	0.4900
PA	0.3252	0.3239	0.3239	0.3239	0.3308	0.3168	0.3360	0.3170	0.3502	0.2944	0.3239	0.3239	0.3210	0.3239
PL	0.4963	0.4297	0.4152	0.4249	0.4562	0.4398	0.4286	0.4161	0.4624	0.4038	0.4197	0.3932	0.4429	0.3868
PW	0.3874	0.4021	0.4021	0.3808	0.4228	0.4063	0.3856	0.3846	0.4325	0.3696	0.4439	0.4021	0.4075	0.4021
PY	0.3760	0.4016	0.3760	0.3760	0.3709	0.3212	0.3604	0.3838	0.3760	0.4220	0.3719	0.3760	0.3760	0.3760
S	0.3907	0.3884	0.3617	0.3937	0.4277	0.3852	0.3917	0.3734	0.4460	0.3680	0.3660	0.3789	0.3815	0.3849
Y	0.6412	0.5204	0.5204	0.4159	0.5936	0.5176	0.5204	0.3410	0.6132	0.5204	0.5204	0.5204	0.5204	0.5204

Assessing Reliability of the Relationships

The correlation coefficients for each of the fitted biomass and volume relationship were generated. A strong relationship was expected because of the relationship between volume, biomass and wood fibre density: Density = biomass / volume. In the absence of measurement error, any pair of the three attributes can be used to predict the other.

Correlations ranged from 0.3708 to 1.0000 (Table 5, Table 14, Table 15, Table 16). The lowest correlation (0.3708) was for Yellow pine (*Pinus ponderosa* - Py) bark biomass in the IDF BEC zone (Table 6b). The majority of the values for the different components in the different BEC zones were higher than 0.9000. This indicates that there are strong relationships between whole-stem volume and the different components of tree biomass.

⁶ Where no sample data existed, an Sp0 average ratio was substituted. This ratio was computed as a mean of the Sp0 ratios across several BECs that had computed ratios.

Table 5. Correlation coefficients for the fitted bole (wood) biomass and whole stem volume at the 4.0cm minimum DBH level for the different Sp0s.

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	1.0000		0.9968	1.0000	0.9950	0.9990	0.9975	0.9974	0.9987	0.9983	1.0000	0.9984	0.9966	1.0000
AT	0.9999		0.9965		0.9982	0.9997	0.9981	0.9995		0.9979	1.0000	0.9993	0.9992	0.9991
B	0.9934		0.9978	0.9998	0.9977	0.9969	0.9976	0.9954	0.9985	0.9972		0.9990	0.9961	0.9977
C				0.9982	0.9890	0.9968	0.9915	0.9987	0.9942	0.9998	1.0000	1.0000	0.9999	
D			0.9949	0.9948	0.9963	0.9874	0.9971	0.9977	1.0000	0.9973	0.9994	0.9491	0.9885	
E	1.0000		0.9930	0.9985	0.9965	0.9979	0.9964	0.9983		0.9985	0.9900	0.9973	0.9962	0.9926
F	0.9974	0.9930		0.9801	0.9840	0.9954	0.9916	0.9914	0.9914	0.9924		0.9969	0.9929	
H	0.9926			0.9939	0.9928	0.9990	0.9984	0.9997	0.9860	1.0000			0.9994	
L	0.972		0.9957		0.9971	0.9963	0.9916	0.9927		0.9970	1.0000		1.0000	0.9988
MB				0.9756	0.9862	0.9953	0.9800	0.9923		0.9044			0.9441	
PA	0.9989				0.9985	0.9987	0.9995	0.9999		0.9981				
PL	0.9952		0.9997	0.9989	0.9962	0.9939	0.9978	0.9986	0.9963	0.9938	0.9999	0.9966	0.9989	0.9991
PW	0.9973			1.0000	0.9973	0.9927	0.9953	0.9987	0.9981	0.9984			0.9984	
PY	0.9986	0.9978			0.9568	0.9754	0.9911	0.9929		0.9967	0.9953			
S			0.9957	0.9988	0.9940	0.9974	0.9954	0.9991	0.9974	0.9982	1.0000	0.9989	0.9980	0.9995
Y	0.9986				0.9926	0.9859			0.9939					

In the initial planning, we envisaged that ground-sample attributes would be used in VDYP7 to predict whole-stem volume at the 4.0cm DBH utilization level by species for use in developing the coefficients. However, the conversion factors delivery deadline of July 30 could not be met using VDYP Phase I estimates. The ground sample volumes were used instead. If the volumes used in computing the conversion factors had been generated by VDYP7 the effects of model bias would have been taken into account to some extent. During the application of the volume-to-biomass conversion factors to the inventory volumes, the predicted volumes will include both VDYP7 model and attribute biases. The magnitude of these biases is unknown.

The longer term plan is to incorporate biomass estimation procedures directly into VDYP7.

APPLICATION OF BIOMASS FACTORS

Several applications of the biomass factors are described below.

Estimation of Biomass at the 4.0 utilization level for a VRI

The application of the computed volume to biomass conversion factors to the inventory occurs in several steps. The procedure is illustrated with a sample polygon.

1. Generate whole stem volume used to generate whole stem volume at the 4.0cm utilization level (wsv_ha) by species for each polygon of interest using VDYP7. The species are used to identify the Sp0 to be used in the application of the conversion factors.
2. Convert volume to biomass component using the regression coefficients in Table 3 (bole), Table 10 (branches), Table 11 (bark), and Table 12 (foliage).
3. Sum the component biomass by species to get the total biomass by species.

4. Sum the species biomass to get the total polygon biomass for stems with Dbh \geq 4.0 in T/ha.

Table 6. Biomass estimation is illustrated for a sample polygon in the ESSF BEC zone.

Species	Sp0	Whole stem volume (4.0cm) (m ³ /ha)	Conversion factor				Biomass (4.0 cm) (T/ha)				Total
			Bole (wood)	Branches	Bark	Foliage	Bole (wood)	Branches	Bark	Foliage	
FDI	F	60	0.3804	0.1082	0.0760	0.0374	22.8	6.5	4.6	2.2	36.1
FDC	F	30	0.3804	0.1082	0.0760	0.0374	11.4	3.2	2.3	1.1	18.1
SS	S	20	0.3852	0.0662	0.0406	0.0334	7.7	1.3	0.8	0.7	10.5
SW	S	10	0.3852	0.0662	0.0406	0.0334	3.9	0.7	0.4	0.3	5.3
Total		120					45.8	11.7	8.1	4.4	69.9

Given the biomass at the 4.0 utilization level, estimate biomass for other utilizations

Once biomass is estimated at the 4.0 utilization level, it can be converted to biomass at other utilization levels. The procedure is illustrated with a sample polygon, converting to utilization at the 4.0 to 2.0 utilization levels.

1. Generate the biomass estimates by BEC and species at the 4.0cm utilization level (T/ha) by species for each polygon of interest.
2. Convert the biomass at the 4.0 utilization to another utilization by sp0, BEC and component using the appropriate coefficients in the workbook Results_ratios.xlsx.

Table 7. Conversion of biomass at the 4.0 cm utilization level to the 2.0 utilization level is illustrated for a sample polygon in the ESSF BEC zone.

Species	Sp0	Biomass (4.0 cm) (T/ha)				Conversion from 4 to 2cm				Biomass (2.0 cm) (T/ha)				Total
		Bole (wood)	Branc hes	Bark	Foliage	Bole (wood)	Branches	Bark	Foliage	Bole (wood)	Branc hes	Bark	Foliage	
FDI	F	22.8	6.5	4.6	2.2	1.0000	1.0001	1.0000	1.0002	22.8	6.5	4.6	2.2	36.1
FDC	F	11.4	3.2	2.3	1.1	1.0000	1.0001	1.0000	1.0002	11.4	3.2	2.3	1.1	18.1
SS	S	7.7	1.3	0.8	0.7	1.0003	1.0058	1.0040	1.0074	7.7	1.3	0.8	0.7	10.5
SW	S	3.9	0.7	0.4	0.3	1.0003	1.0058	1.0040	1.0074	3.9	0.7	0.4	0.3	5.3
Total		45.8	11.7	8.1	4.4					45.8	11.7	8.1	4.4	70.0

Estimation of Biomass at another utilization level from volume at that same utilization level

If volume is available for a utilization level other than 4.0cm, it can be converted to biomass at the same utilization level using the conversion factors in Results_selectData.xls. The coefficients in Results_selectData.xls convert volume at a given utilization to biomass at the same utilization level. The procedure is illustrated with a sample polygon.

1. Convert volume to biomass component using the conversion factors in Results_selectData.xls by sp0, BEC component and appropriate utilization level.
2. Sum the component biomass by species to get the total biomass by species.
3. Sum the species biomass to get the total polygon biomass for stems with Dbh \geq 4.0 in T/ha.

Table 8. Biomass estimation at the 7.5 cm utilization level is illustrated for a sample polygon in the ESSF BEC zone.

Species	Sp0	Whole stem volume (7.5cm) (m ³ /ha)	Conversion factor				Biomass (7.5 cm) (T/ha)				Total
			Bole (wood)	Branches	Bark	Foliage	Bole (wood)	Branches	Bark	Foliage	
FDI	F	54	0.3813	0.1085	0.0761	0.0376	20.6	5.9	4.1	2.0	32.6
FDC	F	27	0.3813	0.1085	0.0761	0.0376	10.3	2.9	2.1	1.0	16.3
SS	S	18	0.3850	0.0664	0.0407	0.0333	6.9	1.2	0.7	0.6	9.5
SW	S	9	0.3850	0.0664	0.0407	0.0333	3.5	0.6	0.4	0.3	4.7
Total		108					41.3	10.6	7.3	3.9	63.1

In the LRDW, all the biomass components will be available by species. Users of the inventory data will be able to extract information selectively if they wish.

During the derivation of the regression coefficient, the independent variable was whole stem volume at the 4.0cm utilization level. That volume was derived from tree measurements. It would have been more appropriate to use volume derived from VDYP7 with photo interpreted inputs. Alternatively, it could have been derived from VDYP7 with ground based attributes.

The historic sample database does not have current photo interpreted attributes. As for the use of ground attributes as input for VDYP7, there was lack of reliable age data at the BEC and Sp0 level. Therefore the ground volume was used.

From a regression theory perspective, this was the appropriate thing to do, because ground volume has limited measurement error. According to Neter & Wasserman (1974), one of the key conditions for getting the best linear unbiased estimates (BLUE) of regression coefficients is that the independent variable(s) should have no measurement error.

In the case of using photo-based attributes to predict VDYP volume, the independent variable would have two major sources of error, i.e., attribute error caused by photo estimation, and model error resulting from the fact that VDYP7 may not work well on some local areas.

In the case of using ground attributes to predict VDYP7 volume, the main source of error in the volume estimates would be VDYP7 prediction errors.

Assuming the ground measured volumes have no error, and given the linear model with no intercept is appropriate, it reasonable to conclude that the regression coefficients presented in Tables 3, 10, 11, and 12 are unbiased estimations of the underlying relationships between Whole stem volume (4.0cm+) and various components of biomass.

CONCLUSIONS & RECOMENDATIONS

The estimation of biomass is an evolving process. In this project we identified a number of weaknesses in the process. The issues tended to fall into two different categories: data source issues and technical / computational - issues.

The 109 tree biomass equations came from all published, individual tree biomass equations applicable to tree species found in Canada and northern areas of the U.S. (Boudewyn, et al, 2007). The Standish, et el (1985) equations were included in the tree biomass estimation. Some of the equations might not be performing well in some Eco-zones of British Columbia. The potential errors that could arise from equation sources have been somewhat mitigated by using tree species wood density information to modify initial biomass estimates when they seemed to be unrealistic.

Some measured tree attributes may have been in error. For instance, some trees had large diameters, but very short heights, suggesting that some stumps may have been misclassified as trees. For trees where only DBH was initially available predicted heights were capped.

Heterogeneity of variance for some BEC and Sp0 combinations was not addressed in this round of analysis. An appropriate weighting is required in order to resolve the problem. Considerable time will be needed to develop such a weighting methodology.

The number of sample observations for the different BEC and Sp0 combination varied considerably, and no attempt was made to merge strata cells with small sample sizes. The sample distribution was not a reflection of the abundance of any given Sp0 in relation to other Sp0s within a BEC zone. Never the less, we believe that the information used was the best available for determining the underlying relationships between biomass and whole-stem volume for the different strata.

In spite of the few issues, the volume-to-biomass conversion factors that are discussed in this report are quite sound for predicting biomass at the polygon level.

Further analysis and confirmation of the computed relationships will continue in future. There are opportunities to improve the methodologies used and to eliminate sources of potential error where they exist.

- Include correction factor for bias in (eqn. 1).
- Use VDYP7 to estimate whole stem volume.
- Investigate adding biomass estimation equations to VDYP7.

REFERENCES

- Baskerville, G. L. 19981. Use of logarithmic regression in the estimation of plant biomass. *Can. J. For. Res.* 2:49-53.
- Bartram C., 1997. Height Diameter Model Comparison - an Evaluation for the Inventory Prediction System. An internal report produced for the Ministry of Forests and Range.
- Boudewyn, P., X. Song, S. Magnussen & M.D. Gillis, 2007. Model-based, volume-to-biomass conversion for forests and vegetated land in Canada. Info report – BC-X-411
- Gonzalez, J.S., 1990. Wood density of Canadian tree species. Northwest Region. Info Report –NOR-X-315.
- Hayes, J.P. & Shonkwiler, J.S. (2006) Allometry, antilog transformations, and the perils of prediction on the original scale. *Physiological and Biochemical Zoology*, 79, 665–674.
- Lambert M.-C., C.H. Ung and F Raulier, 2005. Canadian national tree aboveground biomass equations. *Can. J. For Res.* 35: 1996-2018.
- Morgan, D., 2010. Manager, Forest Biometrics Unit, Sustainable Resource Development, Alberta, Canada. Personal communication.
- Neter, J. And W. Wasserman, 1974. *Applied Linear Statistical Models – Regression, Analysis of Variance and Experimental Designs*. Published by Richard D. Irwin, Inc
- Penner, M., K. Power, C. Muhairwe, R. Tellier, and Y. Wang, 1997. Canada’s forest biomass resources: deriving estimates from Canada’s forest inventory. PFC, Canadian Forest Service. Info. Report-X-370.
- Standish, J.T., G.H. Manning and J.P. Demearschalk, 1985. Development of biomass equations for British Columbia tree species. Info Report BC-X-264. Pacific forest research centre.
- Ung C.-H., P. Bernier, and X.-J. Guo, 2008. Canadian national biomass equations: new parameter estimates that include British Columbia data. *Can. J. For. Res.* 38:1123-1132.
- Wiant, H.V. Jr., E.J. Harner. 1979. Percent bias and standard error in logarithmic regression. *For. Sci.* 25:167-168.

APPENDIX A

Table 9. The Volume to Biomass Project Plan dated March 17, 2010 is given.

Step	Description	Start	End	Who	# of days required	Status
Stage 1 – Tree Biomass						
1.	Reproduce the dataset the CFS used to fit their equations	09/12/12	09/12/23	Alf	3	Done
2.	Describe and document the contents of the CFS standard tree-level table	09/12/09	10/01/15	Wenli	4	Done
3.	Assemble TSP, PSP, audit, NFI, CMI and VRI data in the standard CFS table	09/12/15	10/01/31	Alf	5	Done
4.	Attach ecozone & BEC zone to each tree in the table	09/12/15	10/01/31	Alf	2	Done
5.	Attach biomass estimation equations to each tree in each sample?	10/02/01	10/02/15	Alf/Wenli	10	Done
6.	Recompile audit and VRI Samples	10/02/26	10/02/26	Alf	1	Done
7.	Determine what stratification will be used in data analysis (BEC or ecozone?)	10/02/16	10/02/27	Wenli/Sam	2	Done
8.	Summarise tree data by species, by plot (or cluster of plots (Note: include both species number and species code in the analysis data). See compilation options below: <ol style="list-style-type: none"> 1. Compile the audit data, but set it aside for comparing predicted biomass against calculated. 2. Compile the PSP, VRI, CMI & NFI data to the 4.0cm minimum DBH level 3. Do a separate compilation for trees between 4.0cm and 7.5cm in DBH for the data used in compilation #2. 4. Compile all data, excluding the audit, at the 7.5 cm DBH level 	10/01/03	10/03/15	Wenli	5	Done
9.	Produce bole biomass report by BEC and species/genus	10/03/16	10/03/31	Sam	5	In Progress
10.	Fit Branch, sapling, foliage & bark functions as per CFS report.	10/01/04	10/04/30	Wenli	15	Done
11.	Report on all components of tree biomass by species, by ecozone & by BEC	10/01/05	10/05/30	Sam	15	Done
Stage 2 – Stand level biomass						
12.	Merge plot-summary data from stage 1 with VDYP7 predicted volumes at the 7.5cm DBH ? level	10/01/06	10/06/30	Wenli	20	(Equivalent) Done
13.	Stratify the data by BEC and Sp0	10/07/02	10/07/31	Wenli/Sam	10	Done
14.	Fit stand-level volume-to-biomass conversion models. (Use new equation forms for BC)	10/08/01	10/08/31	Wenli	20	Done
15.	Produce tables of coefficients for conversion of inventory volume to biomass	10/09/01	10/09/30	Sam	15	Done
Stage 3 – Report						
16.	Draft Report with equations	10/09/30	10/10/08	Sam	20	Done
Stage 4 – Attach biomass to forest cover polygons						
17.	Apply equations to forest cover polygons		10/11/26	James/Tim	10	In progress
18.	Final Report		10/12/22		20	In progress
	Estimated Total FTE days (combined)			Wenli/Sam /Alf	182	

APPENDIX B

Table 10. Biomass (tonnes/ha) summary data by BEC zone and genus (SP0)

BEC	SP0	N	Height (m) Live	Age	Wood density (live)	Wood density (dead)	Lorey height (m)	Stems/ha (live)	BA (m ² /ha) (live)	Whole stem volume (m ³ /ha) (live)	Biomass (T/ha) (live)				
											Bole (wood)	Bark	Branches	Foliage	Total
AT	AC	2	26.8		504		26.8	6	1	9.9	5.2	0.8	1.3	0.1	7.4
AT	AT	4	16.6	34	436	425	17.5	57	1.7	14.3	6.5	1.4	1.1	0.2	9.3
AT	B	219	14.9	103	411	397	17.9	736	23.6	173	69.2	9.6	17.6	16.5	113
AT	C	1	28.5		226	320	28.5	13	1.3	15.6	3.7	0.5	0.8	0.4	5.5
AT	E	2	17.0		569		17	8	0.4	2.7	1.6	0.3	0.4	0.1	2.4
AT	F	10	22.6		690	475	23.8	18	1.7	14.7	5.7	1.2	1.6	0.5	9
AT	H	23	16.9	135	565	548	18.4	393	15.6	116	55.6	9.2	9	4.5	78
AT	L	9	17.5	21	790	796	19.9	74	2.6	18.7	8.5	1	0.5	0.2	10
AT	PA	52	13.6	57	326	321	14.3	247	9.4	57.8	18.9	2.8	3.9	1.3	27
AT	PL	54	16.7	80	514	495	17.4	281	10.6	71	35.6	3.5	3.9	3.5	47
AT	PW	5	15.0		391	399	17.2	13	0.6	4.1	1.6	0.2	0.3	0.2	2.2
AT	S	183	19.9	93	406	400	22.4	180	11.9	104	40.7	4.4	7.7	4	57
AT	Y	3	11.9	183	432	351	15.4	686	18.2	117	69.3	4.9	6.3	5.6	86
BG	AT	1	12.2		416		12.2	2	0	0.1	0	0	0	0	0
BG	F	10	14.1	99	881	478	17.9	498	17.4	105	44.3	8.1	13.2	6.1	72
BG	PY	3	9.9	70	359	396	12.7	148	5.5	26.5	10.6	2.2	6.2	2.3	21
BWBS	AC	1717	20.2	40	433	432	21.4	177	7.5	67.3	28.9	4.8	4.5	0.6	39
BWBS	AT	3168	19.6	45	415	409	20.4	484	11.7	104	42.3	9.5	4.2	0.8	57
BWBS	B	714	13.7	67	422	381	15.7	269	5.7	39.1	14.3	2.4	2.4	1.9	21
BWBS	D	110	7.0	24	609	379	7.4	169	0.5	2.1	0.9	0.1	1.7	0.4	3
BWBS	E	1679	15.6	34	564	560	16.4	254	3.3	22.2	12.3	2.2	2.4	0.6	17
BWBS	F	14	13.5		483	517	13.5	121	5	21.9	10.6	1.4	4.5	2.7	19
BWBS	L	211	14.6	58	449	443	15	170	2.5	15.4	6.8	0.9	1.1	0.4	9.1
BWBS	PL	2867	17.8	57	421	421	18.6	633	12.9	113	47.3	4.3	4.5	2.8	59
BWBS	S	4472	16.4	63	398	389	18.7	669	15.8	135	49.9	6.6	5.6	5.4	68
CDF	AC	2	28.6	16	324		28.6	253	4.3	44.3	14.5	2.1	3.5	0.3	20
CDF	B	56	14.1	68	656	874	16.3	81	3.9	64.5	20.6	3.2	3.3	3.1	30
CDF	C	94	13.5	69	412	412	16.6	224	6.7	68.2	18.8	2.6	3.9	2.8	28
CDF	D	61	22.2	41	456	422	22.9	246	9.6	106	46.8	6.9	8.4	4.1	66
CDF	E	30	14.4		542	526	14.6	40	0.6	5.3	2.7	0.6	0.4	0.2	4
CDF	F	169	23.7	68	504	670	28.2	783	40.3	430	209	32	20.5	10.2	272
CDF	H	83	14.4	53	683	894	16.4	127	2.3	20.4	8.1	1.3	2.3	1.2	13
CDF	MB	48	17.2	55	599	521	18.8	64	2.1	23.4	10.7	1.8	2.7	0.2	16
CDF	PL	42	20.8	63	443	430	21.6	552	11.2	107	46.3	4.7	5.2	4.8	61

BEC	SP0	N	Height (m) Live	Age	Wood density (live)	Wood density (dead)	Lorey height (m)	Stems/ha (live)	BA (m ² /ha) (live)	Whole stem volume (m ³ /ha) (live)	Biomass (T/ha) (live)				
											Bole (wood)	Bark	Branches	Foliage	Total
CDF	PW	7	16.3	24	443	662	16.5	35	2.3	23.4	8.9	0.9	1.6	0.7	12
CDF	S	8	20.4	121	414	609	22	102	4.2	52.4	20.4	2.3	4.8	4.3	32
CDF	Y	1	10.8		367		12.6	64	1.3	7.5	3.1	0.3	0.5	0.5	4.5
CWH	AC	324	29.2	31	449	409	30.2	182	13.5	172	81.9	12	19.6	1.9	115
CWH	AT	95	18.5	14	432	426	19.2	102	3.2	29.2	12.7	2.7	2.3	0.5	18
CWH	B	5585	19.7	85	380	379	26.2	296	14.3	183	69.2	9	14	14.3	107
CWH	C	7677	20.2	102	574	624	25.3	232	21.3	198	61.2	8.2	13.5	7.1	90
CWH	D	1999	21.2	25	451	445	22	156	5.5	55.7	25.6	3.8	4.9	2.3	37
CWH	E	889	15.7	21	569	620	16.4	131	2.3	17.9	9.7	1.8	2.5	0.6	15
CWH	F	4225	29.2	74	615	824	32.1	366	26.2	292	157	23	13.3	5.9	199
CWH	H	10456	20.1	97	519	530	26.6	543	28	332	136	19	20	8.7	184
CWH	L	7	15.2		522	522	15.9	91	2.4	14.6	7.9	0.9	0.6	0.2	9.5
CWH	MB	544	18.3	33	706	647	20.2	111	4.2	42.4	22.2	4.3	3.6	0.3	30
CWH	PA	23	18.2	56	320	310	19	59	4.1	30.4	10	1.5	2.1	0.7	14
CWH	PL	1184	17.7	59	485	478	18.8	201	5.7	46.6	21.9	2.2	2.4	2.2	29
CWH	PW	882	23.3	39	414	409	24.4	30	1.8	22.7	9.2	0.9	1.5	0.7	12
CWH	PY	3	13.9		373	398	14.4	19	0.5	2.7	1	0.1	0.2	0.1	1.4
CWH	S	3317	28.0	76	432	418	30.8	126	14.2	187	79.4	8.4	14.3	10.1	112
CWH	Y	1848	19.6	143	491	507	23	184	13.2	118	67.5	4.3	4.9	3.6	80
ESSF	AC	121	21.0	40	512	503	21.4	43	2.1	17.9	9.5	1.4	2.3	0.2	13
ESSF	AT	404	17.4	23	453	448	17.8	106	2.7	20.3	9.4	2.1	1.6	0.3	13
ESSF	B	8245	15.5	89	396	385	19.3	628	17.9	143	54.7	7.6	14.2	13.2	90
ESSF	C	906	16.6	77	605	400	20.3	193	14.3	128	38	5.2	8.8	4.6	57
ESSF	D	92	5.1	25	836	1016	5.3	216	0.4	0.9	0.5	0.1	0.6	0.7	1.8
ESSF	E	156	12.0	33	591	564	12.4	213	1.8	9.1	5.1	1	1.4	0.4	7.8
ESSF	F	1408	22.0	72	652	583	23.7	134	8.4	68.7	26.8	5.3	7.7	2.8	43
ESSF	H	1604	15.6	96	526	465	18.6	247	11.4	103	44.7	6.5	7.4	3.4	62
ESSF	L	441	25.8	59	641	705	26.9	69	4.1	38.4	18.1	2.4	0.7	0.2	22
ESSF	MB	8	4.1		466		4.3	117	0.2	0.5	0.4	0.1	0	0	0.5
ESSF	PA	544	15.0	71	312	311	15.8	175	8.1	58.7	18.7	2.7	3.9	1.3	27
ESSF	PL	3785	19.9	69	465	454	20.7	498	14.5	126	57	5.7	6.3	5.7	75
ESSF	PW	399	23.6	40	392	385	24.4	39	2.5	25.7	10.3	1	1.8	0.8	14
ESSF	PY	9	26.7	173	381	467	27.1	108	5.1	50.2	16.9	3.2	6.9	2.3	29
ESSF	S	7861	20.6	96	427	394	24.1	258	14.2	141	54.4	5.9	10.2	5.4	76
ESSF	Y	21	15.0	9	442	470	17.3	239	4	28.9	14.8	1.1	1.4	1.4	19
ICH	AC	762	24.9	40	502	486	25.6	58	6.1	72.2	38	5.4	9.1	0.9	53
ICH	AT	2053	19.9	31	442	435	20.6	154	3.6	30.9	13.8	3	2.4	0.5	20
ICH	B	4697	17.1	62	413	386	20.4	202	6.3	58.5	22.6	3.1	5.5	5.2	36

BEC	SP0	N	Height (m) Live	Age	Wood density (live)	Wood density (dead)	Lorey height (m)	Stems/ha (live)	BA (m ² /ha) (live)	Whole stem volume (m ³ /ha) (live)	Biomass (T/ha) (live)				
											Bole (wood)	Bark	Branches	Foliage	Total
ICH	C	6492	16.3	77	735	441	20.7	351	17.2	152	47.4	6.5	10.4	6.2	70
ICH	D	226	7.4	26	637	495	7.9	132	0.5	2.7	1.2	0.2	1	0.4	2.7
ICH	E	3120	17.0	32	547	547	18.1	182	3.4	26.3	14.2	2.3	3.7	0.9	21
ICH	F	5215	21.8	67	815	694	24.5	297	12.3	112	42	8.1	12.2	4.9	67
ICH	H	5921	16.4	81	575	511	20.9	494	16.8	157	67.7	9.8	12.4	5.8	96
ICH	L	2411	25.5	61	706	891	27.3	162	6.6	64.9	29.2	3.8	1.3	0.4	35
ICH	MB	280	8.2	60	466	466	8.8	125	0.5	2	1.3	0.2	0.2	0.1	1.7
ICH	PA	13	14.5	51	297	315	15.1	47	3	23.7	7.8	1.1	1.6	0.5	11
ICH	PL	3297	21.4	50	444	427	22.1	357	8.7	86.7	37.8	3.8	4.2	3.8	50
ICH	PW	2786	23.6	44	392	374	25.3	75	3.5	38.9	15	1.5	2.8	1.3	21
ICH	PY	143	22.2	57	369	352	23.8	56	4.9	50.5	17.8	3.7	6.4	1.9	30
ICH	S	5479	20.9	70	468	422	23.9	160	7.3	77.9	30.3	3.3	5.8	3.1	43
IDF	AC	105	22.5	42	473	465	23.3	62	5.8	64.2	30.2	4.3	7.2	0.7	42
IDF	AT	1515	15.0	33	442	444	15.7	140	2.6	20	9.1	2	1.6	0.3	13
IDF	B	353	13.9	45	428	370	15.9	108	2.5	20.5	7.5	1.1	2.1	1.9	13
IDF	C	447	12.5	50	761	437	15.9	281	7.6	60.9	18.5	2.6	4.2	3	28
IDF	D	40	12.8	30	533	423	13.5	70	0.8	7.6	3.1	0.5	0.8	0.4	4.8
IDF	E	918	14.3	28	490	498	15.3	133	2.1	15.6	8.3	1.3	2.2	0.6	12
IDF	F	4844	15.7	91	1356	1144	20.7	592	18.8	142	56.5	11	16.6	7	91
IDF	H	120	14.8	67	647	555	18.2	146	5.1	50.7	21.6	3.1	3.8	1.7	30
IDF	L	594	20.9	83	522	522	23.8	230	7.2	63	30.3	3.8	1.5	0.5	36
IDF	MB	164	8.0	21	466	466	8.7	168	0.7	3.2	1.8	0.3	0.3	0.1	2.6
IDF	PA	6	13.3	96	311	295	14.4	52	2.1	16.9	5.3	0.8	1.1	0.4	7.6
IDF	PL	3485	16.1	57	435	434	17.5	493	9.3	78.1	32.9	3.3	3.7	3.5	43
IDF	PW	83	22.4	73	382	376	24	33	1.6	19.3	7.4	0.7	1.3	0.6	10
IDF	PY	954	16.4	91	383	383	19.1	79	4.1	31.6	12	3	6.1	1.9	23
IDF	S	1515	14.7	54	529	461	17.2	150	4.1	36.1	13.7	1.7	3.5	2.1	21
IDF	Y	1	8.8		341		8.8	12	0.1	0.6	0.2	0	0.1	0.1	0.4
MH	AC	4	30.2		476		30.6	16	3	32.7	16	2.3	3.8	0.4	23
MH	B	537	20.3	115	379	378	26.6	427	29.3	343	133	17	26.7	26.6	203
MH	C	87	21.2	82	431	332	24.2	79	8	74.3	22.5	3	5.1	2.6	33
MH	D	2	25.8	49	452	356	25.8	98	9.3	98.3	48.7	7.3	7.4	4	67
MH	E	1	17.1		545	550	17.1	10	0.2	1.2	0.6	0.1	0.2	0	1
MH	F	56	27.5	114	790	856	28.9	99	16.2	157	95.9	13	7.1	2.7	119
MH	H	557	21.2	152	530	504	26.7	384	31.8	293	141	20	18.8	8	188
MH	PA	3	12.0	165	350	336	12	12	1	4.8	1.7	0.2	0.3	0.1	2.4
MH	PL	9	17.3	127	513	477	18.3	266	10.4	78.5	37.6	3.7	4.1	3.7	49
MH	PW	37	22.6	65	406	398	23.1	61	1.8	17.3	7.4	0.7	1.6	0.8	11

BEC	SPO	N	Height (m) Live	Age	Wood density (live)	Wood density (dead)	Lorey height (m)	Stems/ha (live)	BA (m ² /ha) (live)	Whole stem volume (m ³ /ha) (live)	Biomass (T/ha) (live)				
											Bole (wood)	Bark	Branches	Foliage	Total
MH	S	73	27.9	92	431	413	30.3	65	8.8	104	44.6	4.7	7.6	4.8	62
MH	Y	197	21.4	213	512	542	24.8	151	17.6	166	99.6	6.1	6.7	4.7	117
MS	AC	47	22.4	9	480	448	22.9	28	3.2	35.9	17.2	2.5	4.1	0.4	24
MS	AT	416	17.4	20	442	438	18.2	94	2.1	17.5	7.8	1.7	1.3	0.3	11
MS	B	1534	14.1	61	440	424	17	368	6.6	47.9	18.2	2.7	5.6	5.1	32
MS	C	171	13.8	42	694	276	16.2	139	5.8	53.1	14.6	2	3.4	2.1	22
MS	D	51	6.3		695	530	6.9	217	0.6	2.3	1	0.1	1.8	0.6	3.5
MS	E	208	14.4	12	597	567	15.1	87	1.3	9.2	5.1	0.8	1.3	0.4	7.5
MS	F	1347	18.7	74	944	684	21.6	288	11.4	89.5	35.9	6.8	10.5	4.3	57
MS	H	62	15.3	54	505	444	17.3	80	2.7	22.6	9.7	1.4	2	1	14
MS	L	468	22.2	79	522	522	24.6	215	7.5	66	32.1	4.1	1.4	0.5	38
MS	MB	17	7.8		466		9	104	0.3	1.4	0.8	0.1	0.1	0	1.1
MS	PA	43	12.7	40	299	296	13.4	116	4.1	29.6	9	1.3	1.9	0.6	13
MS	PL	2754	18.6	68	413	406	19.7	978	20.3	188	77.2	7.8	8.6	8	102
MS	PW	59	19.7	21	381	370	21.4	81	2.4	23.1	8.7	0.9	2	1.1	13
MS	PY	38	16.9	54	399	405	18.1	41	1.5	10.9	4.5	0.8	2.1	0.7	8.2
MS	S	2005	17.1	74	487	469	20.3	278	9.8	95.3	35.5	4.1	7.7	4.4	52
PP	AC	2	16.4		469	497	16.4	12	0.4	2.2	1	0.1	0.2	0	1.4
PP	AT	16	13.4	33	443	453	14.1	37	1.2	12.1	5.6	1.2	1	0.2	8
PP	B	1	17.3		349	335	17.6	12	0.3	2.7	0.9	0.1	0.2	0.2	1.5
PP	C	2	6.3	64	481		6.5	29	0.2	0.7	0.3	0	0.1	0.1	0.5
PP	E	4	15.8		476		16.9	31	0.3	2.4	1.2	0.2	0.3	0.1	1.8
PP	F	248	13.0	90	445	445	17	352	9.7	57.3	24.8	4.5	7.5	3.6	40
PP	L	4	15.9	18	522	522	17.8	148	2.3	15.3	8.2	0.9	0.5	0.2	9.7
PP	PL	12	14.0	30	435	431	14.3	103	1.7	13.4	5.7	0.6	0.6	0.6	7.5
PP	PW	1	18.3		444		18.3	1	0.4	2.2	1	0.1	0.1	0.1	1.3
PP	PY	250	13.6	96	347	357	16.7	219	7.7	52.6	19.2	4.1	10.6	3.7	38
PP	S	3	14.8	58	663	389	20.2	212	8.7	76.4	28.1	3.1	4.8	3.4	39
SBPS	AC	37	19.2	34	471	473	20.4	81	3.7	29.2	13.8	2	3.3	0.3	19
SBPS	AT	479	16.4	36	446	445	17.1	209	3.8	27.7	12.6	2.8	2.2	0.4	18
SBPS	B	98	14.3	42	445	386	16.1	199	3.5	24.1	9.3	1.3	2.6	2.8	16
SBPS	C	2	16.1		427	305	16.2	44	2.3	18.8	5.1	0.7	1.3	0.8	7.9
SBPS	D	7	5.4		826	1004	5.4	96	0.2	0.5	0.2	0	0.2	0.2	0.7
SBPS	E	57	15.4	30	576	939	16	72	1.3	8.6	4.7	0.8	1.2	0.3	7.1
SBPS	F	226	16.5	79	445	445	20.2	255	9.3	68.7	27.6	5.3	8	3.2	44
SBPS	PL	1342	15.8	63	403	396	17.1	1217	20.4	180	71.5	7.3	8	7.7	95
SBPS	S	769	13.8	61	584	501	15.9	345	7.3	57	22.1	2.9	6.7	4.2	36
SBS	AC	1017	23.3	38	505	490	24	53	4.5	46.6	24.6	3.5	5.9	0.6	35

BEC	SP0	N	Height (m) Live	Age	Wood density (live)	Wood density (dead)	Lorey height (m)	Stems/ha (live)	BA (m ² /ha) (live)	Whole stem volume (m ³ /ha) (live)	Biomass (T/ha) (live)				
											Bole (wood)	Bark	Branches	Foliage	Total
SBS	AT	4163	19.6	37	451	443	20.3	240	5.6	47	21.4	4.7	3.7	0.7	31
SBS	B	6619	14.4	69	432	381	17.8	416	9.9	80.6	30.4	4.3	8.2	7.6	51
SBS	C	185	15.8	55	644	305	19.7	151	13	131	37.4	5	8.1	4.4	55
SBS	D	254	6.5	26	687	730	6.8	177	0.5	1.5	0.7	0.1	1.1	0.4	2.3
SBS	E	2881	17.3	33	595	592	18.1	159	2.9	21	11.8	1.9	3.1	0.8	18
SBS	F	2220	21.5	63	873	763	24	238	9.8	86.9	32.9	6.3	9.6	3.8	53
SBS	H	466	13.0	65	563	465	15.3	190	7.4	59.4	25	3.7	4.8	2.3	36
SBS	L	3	13.7	221	522		13.7	59	2.8	19.5	9.6	1.2	0.6	0.2	12
SBS	MB	24	6.4		466		6.5	50	0.1	0.3	0.2	0	0	0	0.2
SBS	PA	6	14.5	30	305	310	14.8	16	1	7.3	2.3	0.3	0.5	0.2	3.3
SBS	PL	7397	21.3	60	453	439	22.3	597	16.6	162	72.6	7.2	8	7.2	95
SBS	PW	3	21.4	52	406	395	22.3	33	3.2	25.6	10.4	1	1.8	0.8	14
SBS	S	9109	18.7	74	496	441	21.7	369	12.9	123	47.2	5.5	10.6	5.9	69
SWB	AC	58	14.1	28	459	459	15.1	140	3.7	19.2	8.8	1.9	2.3	0.4	14
SWB	AT	188	15.2	37	426	419	15.7	219	4.2	26.4	11.2	2.2	1.5	0.3	15
SWB	B	595	11.2	66	423	398	13.3	547	10	56.4	21.5	3.1	4.8	3.5	33
SWB	E	31	13.0	9	711	600	13.5	58	0.8	4	2.5	0.4	0.5	0.2	3.6
SWB	L	4	13.0		511		13.4	28	0.6	3.3	1.7	0.2	0.4	0.2	2.4
SWB	PL	690	14.0	65	377	379	15	510	10.1	78.1	29.9	3.1	5.2	2.5	41
SWB	S	1025	13.3	76	391	391	15.8	503	13.8	88	34	5.8	7.5	5.1	53

APPENDIX C

Table 11. Coefficients for branch biomass fitted by regression without intercept by BEC zone and genus (Sp0)

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	0.1281	0.1148	0.0620	0.0787	0.1158	0.1295	0.1267	0.1114	0.1200	0.1159	0.1113	0.1150	0.1270	0.1512
AT	0.0781	0.0714	0.0351	0.0718	0.0784	0.0794	0.0769	0.0780	0.0718	0.0750	0.0796	0.0779	0.0778	0.0540
B	0.0958	0.0842	0.0565	0.0410	0.0740	0.0943	0.0890	0.0969	0.0765	0.1140	0.0842	0.1021	0.0957	0.0747
C	0.0498	0.0691	0.0691	0.0536	0.0667	0.0663	0.0662	0.0604	0.0672	0.0566	0.1487	0.0684	0.0568	0.0691
D	0.3486	0.3486	0.7379	0.0768	0.0812	0.5020	0.1299	0.0957	0.0754	0.7003	0.3486	0.3993	0.6871	0.3486
E	0.1571	0.1313	0.0957	0.0774	0.1353	0.1522	0.1366	0.1372	0.1427	0.1408	0.1286	0.1375	0.1426	0.1237
F	0.1059	0.1205	0.2037	0.0456	0.0410	0.1082	0.1032	0.1063	0.0388	0.1101	0.1197	0.1107	0.1050	0.1014
H	0.0669	0.0654	0.0654	0.0996	0.0517	0.0591	0.0635	0.0565	0.0603	0.0667	0.0654	0.0654	0.0642	0.0654
L	0.0268	0.0366	0.0662	0.0366	0.0377	0.0172	0.0187	0.0220	0.0366	0.0186	0.0284	0.0366	0.0282	0.1022
MB	0.0813	0.0813	0.0813	0.0920	0.0778	0.0546	0.1082	0.0935	0.0813	0.0838	0.0813	0.0813	0.0590	0.0813
PA	0.0671	0.0668	0.0668	0.0668	0.0683	0.0654	0.0693	0.0654	0.0723	0.0608	0.0668	0.0668	0.0662	0.0668
PL	0.0549	0.0480	0.0338	0.0470	0.0505	0.0487	0.0475	0.0464	0.0512	0.0449	0.0473	0.0439	0.0489	0.0590
PW	0.0788	0.0691	0.0691	0.0611	0.0630	0.0666	0.0674	0.0622	0.0744	0.0814	0.0670	0.0691	0.0689	0.0691
PY	0.1809	0.2332	0.1809	0.1809	0.0765	0.1547	0.1383	0.2503	0.1809	0.1981	0.2152	0.1809	0.1809	0.1809
S	0.0710	0.0715	0.0341	0.0782	0.0761	0.0662	0.0670	0.0794	0.0786	0.0683	0.0586	0.0980	0.0757	0.0777
Y	0.0464	0.0624	0.0624	0.0713	0.0397	0.0483	0.0624	0.1283	0.0404	0.0624	0.0624	0.0624	0.0624	0.0624

Table 12. Coefficients for bark biomass fitted by regression without intercept by BEC zone and genus (Sp0)

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	0.0768	0.0711	0.0607	0.0472	0.0694	0.0776	0.0759	0.0668	0.0719	0.0695	0.0667	0.0689	0.0761	0.0971
AT	0.1000	0.0914	0.0887	0.0954	0.0893	0.1016	0.0952	0.0998	0.0954	0.0960	0.1019	0.0997	0.0996	0.0812
B	0.0550	0.0532	0.0618	0.0500	0.0491	0.0531	0.0528	0.0511	0.0505	0.0553	0.0483	0.0547	0.0531	0.0564
C	0.0306	0.0408	0.0408	0.0358	0.0423	0.0404	0.0431	0.0390	0.0409	0.0362	0.0665	0.0367	0.0376	0.0408
D	0.0592	0.0592	0.0323	0.0645	0.0670	0.0638	0.0682	0.0615	0.0741	0.0362	0.0592	0.0876	0.0364	0.0592
E	0.1004	0.0940	0.0916	0.1425	0.0886	0.0986	0.0848	0.0839	0.0853	0.0892	0.0741	0.0837	0.0900	0.1097
F	0.0776	0.0755	0.0637	0.0727	0.0727	0.0760	0.0702	0.0725	0.0743	0.0746	0.0746	0.0760	0.0713	0.0732
H	0.0751	0.0615	0.0615	0.0615	0.0548	0.0599	0.0596	0.0571	0.0674	0.0597	0.0615	0.0615	0.0582	0.0615
L	0.0540	0.0580	0.0543	0.0580	0.0612	0.0641	0.0579	0.0597	0.0580	0.0633	0.0524	0.0580	0.0603	0.0530
MB	0.0822	0.0822	0.0822	0.0756	0.0973	0.0726	0.0845	0.0981	0.0822	0.0759	0.0822	0.0822	0.0714	0.0822
PA	0.0476	0.0474	0.0474	0.0474	0.0484	0.0464	0.0492	0.0464	0.0512	0.0431	0.0474	0.0474	0.0470	0.0474
PL	0.0494	0.0427	0.0371	0.0423	0.0455	0.0438	0.0428	0.0419	0.0460	0.0405	0.0429	0.0397	0.0440	0.0396
PW	0.0387	0.0388	0.0388	0.0363	0.0398	0.0389	0.0373	0.0367	0.0417	0.0376	0.0418	0.0388	0.0392	0.0388
PY	0.0873	0.0836	0.0873	0.0873	0.0543	0.0668	0.0836	0.1479	0.0873	0.0852	0.0895	0.0873	0.0873	0.0873
S	0.0419	0.0444	0.0448	0.0429	0.0451	0.0406	0.0413	0.0424	0.0470	0.0400	0.0395	0.0464	0.0421	0.0632
Y	0.0404	0.0418	0.0418	0.0413	0.0362	0.0366	0.0418	0.0595	0.0371	0.0418	0.0418	0.0418	0.0418	0.0418

Table 13. Coefficients for foliage biomass fitted by regression without intercept by BEC zone and genus (Sp0)

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	0.0123	0.0115	0.0062	0.0076	0.0111	0.0125	0.0122	0.0107	0.0115	0.0112	0.0107	0.0111	0.0122	0.0199
AT	0.0160	0.0146	0.0064	0.0145	0.0160	0.0162	0.0157	0.0159	0.0145	0.0153	0.0163	0.0159	0.0159	0.0102
B	0.0898	0.0785	0.0453	0.0404	0.0744	0.0874	0.0835	0.0844	0.0761	0.0976	0.0900	0.1070	0.0878	0.0563
C	0.0269	0.0424	0.0424	0.0306	0.0342	0.0329	0.0349	0.0355	0.0326	0.0295	0.1435	0.0362	0.0294	0.0424
D	0.1319	0.1319	0.1284	0.0373	0.0389	0.3840	0.0489	0.0385	0.0412	0.1348	0.1319	0.3042	0.1630	0.1319
E	0.0293	0.0344	0.0235	0.0373	0.0315	0.0368	0.0321	0.0339	0.0388	0.0320	0.0410	0.0347	0.0349	0.0413
F	0.0328	0.0536	0.1249	0.0218	0.0170	0.0374	0.0388	0.0397	0.0141	0.0416	0.0538	0.0408	0.0396	0.0428
H	0.0322	0.0293	0.0293	0.0506	0.0212	0.0252	0.0278	0.0238	0.0249	0.0298	0.0293	0.0293	0.0285	0.0293
L	0.0090	0.0135	0.0270	0.0135	0.0130	0.0054	0.0062	0.0075	0.0135	0.0060	0.0106	0.0135	0.0094	0.0408
MB	0.0217	0.0217	0.0217	0.0069	0.0057	0.0322	0.0292	0.0195	0.0217	0.0284	0.0217	0.0217	0.0304	0.0217
PA	0.0218	0.0218	0.0218	0.0218	0.0222	0.0213	0.0226	0.0213	0.0235	0.0198	0.0218	0.0218	0.0216	0.0218
PL	0.0489	0.0413	0.0219	0.0422	0.0455	0.0437	0.0430	0.0433	0.0458	0.0411	0.0462	0.0412	0.0435	0.0302
PW	0.0400	0.0309	0.0309	0.0257	0.0245	0.0286	0.0306	0.0263	0.0333	0.0434	0.0264	0.0309	0.0304	0.0309
PY	0.0600	0.0858	0.0600	0.0600	0.0249	0.0523	0.0411	0.0744	0.0600	0.0677	0.0739	0.0600	0.0600	0.0600
S	0.0359	0.0458	0.0336	0.0709	0.0573	0.0333	0.0334	0.0445	0.0576	0.0369	0.0426	0.0579	0.0400	0.0520
Y	0.0348	0.0563	0.0563	0.0693	0.0276	0.0417	0.0563	0.1368	0.0278	0.0563	0.0563	0.0563	0.0563	0.0563

APPENDIX D

Table 14. Correlation coefficients for branch biomass and whole stem volume for a 4.0cm DBH utilization standard

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	1.0000		0.9300	1.0000	0.9950	0.9990	0.9974	0.9973	0.9984	0.9983	1.0000	0.9984	0.9966	0.9780
AT	1.0000		0.8411		0.9981	0.9996	0.9989	0.9995		0.9978	1.0000	0.9992	0.9992	0.9509uu
B			0.9279	0.9951	0.9876	0.9161	0.9568	0.9668	0.9854	0.9266		0.9447	0.9393	0.8847
C				0.9915	0.9738	0.9937	0.9909	0.9859	0.9816	0.9971		1.0000	0.9956	
D			0.8841	0.9811	0.8770	0.7322	0.4980	0.9629	1.0000	0.9256		0.9166	0.8895	
E	1.0000		0.9422	0.9704	0.9954	0.9925	0.9964	0.9979		0.9968	0.9981	0.9973	0.9950	0.9692
F	0.9942	0.9855		0.9728	0.9569	0.9920	0.9850	0.9836	0.9601	0.9868	0.9790	0.9942	0.9867	
H	0.8764			0.7297	0.8727	0.8939	0.8100	0.9217	0.8804	0.9533			0.9396	
L	0.8091		0.9316		0.9753	0.8949	0.8606	0.9046		0.8612	0.9998		0.9977	0.9773
MB				0.8230	0.9791	0.9078	0.9777	0.9898		0.8907			0.8597	
PA	0.9989				0.9984	0.9986	0.9995	0.9998		0.9980			0.9973	
PL	0.9951		0.6556	0.9990	0.9966	0.9942	0.9977	0.9977	0.9968	0.9944	0.9997	0.9973	0.9974	0.8488
PW	0.9422			0.9983	0.9826	0.9706	0.9638	0.9619	0.6209	0.9408			0.9844	
PY		0.9315			0.8846	0.9381	0.6622	0.4067		0.6667	0.7277			
S	0.9611		0.6843	0.9858	0.9815	0.9276	0.9312	0.9126	0.9782	0.9055	0.9962	0.9094	0.8745	0.9072
Y	0.9243				0.9188	0.8433			0.8915					

Table 15. Correlation coefficients for bark biomass and whole stem volume for a 4.0cm DBH utilization standard.

SP0	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	1.0000		0.9719	1.0000	0.9950	0.9991	0.9974	0.9974	0.9978	0.9982	1.0000	0.9983	0.9966	0.9984
AT	1.0000		0.9688		0.9978	0.9996	0.9961	0.9995		0.9979	1.0000	0.9992	0.9992	0.9892
B	0.9945		0.9963	0.9998	0.9976	0.9963	0.9984	0.9984	0.9985	0.9940		0.9930	0.9966	0.9944
C				0.9976	0.9898	0.9971	0.9918	0.9956	0.9946	0.9993	1.0000	1.0000	0.9998	
D			0.8648	0.9944	0.9950	0.8830	0.9817	0.9958	1.0000	0.8367		0.9167	0.5690	
E			0.9843	0.9882	0.8211	0.9724	0.9925	0.9936		0.9925	0.9622	0.9960	0.9878	0.9891
F	0.9958	0.9994		0.9856	0.9847	0.9974	0.9967	0.9972	0.9864	0.9957	0.9970	0.9985	0.9978	
H	0.9437			0.9470	0.9892	0.9857	0.9904	0.9962	0.9394	0.9978			0.9965	
L	0.9920		0.9718		0.9984	0.9940	0.9968	0.9919		0.9958	0.9998		1.0000	0.9157
MB				0.9758	0.9850	0.9078	0.9697	0.9912		0.8689			0.8597	
PA	0.9988				0.9989	0.9986	0.9997	0.9999		0.9981			0.9981	
PL	0.9948		0.9802	0.9989	0.9967	0.9941	0.9974	0.9972	0.9968	0.9944	0.9999	0.9970	0.9969	0.9916
PW	0.9745			0.9999	0.9974	0.9943	0.9962	0.9978	0.9795	0.9969			0.9963	
PY		0.9881	0.9629		0.8846	0.9882	0.6181	0.3708		0.8924	0.7820			
S	0.9950			0.9982	0.9953	0.9890	0.9893	0.9854	0.9949	0.9839	0.9998	0.9793	0.9814	0.9803
Y	0.9939				0.9844	0.9684			0.9782					

Table 16. Correlation Coefficients for foliage biomass and whole stem volume for a 4.0cm DBH utilization standard.

SPO	BEC													
	AT	BG	BWBS	CDF	CWH	ESSF	ICH	IDF	MH	MS	PP	SBPS	SBS	SWB
AC	1.0000		0.7965	1.0000	0.9950	0.9969	0.9974	0.9973	0.9940	0.9981		0.9968	0.9964	0.9849
AT	0.9981		0.7976		0.9973	0.9989	0.9981	0.9989		0.9962	0.9998	0.9984	0.9988	0.9568
B	0.9732		0.9361	0.9968	0.9823	0.9665	0.9841	0.9723	0.9934	0.9417		0.9242	0.9734	0.9371
C				0.9781	0.9808	0.9875	0.9802	0.9358	0.9859	0.9876	1.0000	1.0000	0.9961	
D			0.8846	0.9934	0.9808	0.6415	0.7579	0.9744	1.0000	0.8484		0.9356	0.7921	
E			0.8906	0.9919	0.9467	0.9435	0.9130	0.9529		0.9772	0.9428	0.0023	0.9128	0.9193
F	0.9549	0.9063		0.8862	0.8301	0.9457	0.8861	0.8518	0.8733	0.9050	0.8586	0.9432	0.9002	
H	0.7725			0.6718	0.7365	0.8034	0.6797	0.8508	0.7520	0.976			0.8926	
L	0.7997		0.9436		0.9595	0.8498	0.8062	0.8669		0.7990	0.9969		0.9910	0.7498
MB				0.8249	0.8617	0.8321	0.9191	0.8322		0.7441				
PA	0.9989				0.9968	0.9985	0.9989	0.9991		0.9974			0.9977	
PL	0.9923		0.8598	0.9867	0.9884	0.9878	0.9821	0.9841	0.9975	0.9822	0.9997	0.9705	0.9775	0.9364
PW	0.7127			0.9936	0.9179	0.8824	0.8763	0.8567	0.3226	0.8660			0.9134	
PY		0.9121			0.8846	0.9094	0.6816	0.4230		0.5836	0.6721			
S	0.9084		0.8673	0.9897	0.9008	0.8348	0.8445	0.8517	0.8912	0.8360	0.9983	0.8448	0.7385	0.8861
Y	0.6079				0.7810	0.5238			0.7524					

APPENDIX E

Taken from Ung et al. (2008).

Table 2. Descriptive statistics for DBH, height, and total biomass by tree species.

Species	Trees	DBH (cm)	Height (m)	Total biomass (kg)
Black cottonwood	19	16.7±1.7 (7.4; 30.6)	13.6±1.1 (6.9; 23.5)	102.5±26.2 (13.4; 366.3)
Black spruce	1591	14.0±0.2 (1.6; 38.4)	11.7±0.1 (1.8; 30.1)	74.5±1.9 (0.6; 685.1)
Douglas-fir (coastal)	14	15.6±3.5 (4.5; 50.8)	10.8±2.3 (4.1; 31.2)	166.6±98.9 (4.9; 1394.5)
Douglas-fir (interior)	11	17.6±4.0 (5.6; 39.5)	10.8±2.1 (3.6; 21.7)	193.0±81.9 (5.6; 803.8)
Engelmann spruce	26	24.2±2.6 (5.7; 57.6)	17.5±1.7 (4.4; 40.8)	319.7±82.7 (5.8; 1923.5)
Lodgepole pine	280	16.1±0.5 (2.5; 48.9)	13.5±0.4 (2.3; 39.6)	128.4±10.0 (0.8; 1180.9)
Pacific silver fir	28	14.3±1.1 (4.5; 30.4)	10.3±0.7 (3.1; 18.4)	64.2±11.9 (4.2; 313.3)
Red alder	11	12.2±0.9 (9.3; 19.5)	11.8±0.6 (7.4; 14.5)	36.7±9.3 (12.4; 123.8)
Sitka spruce	12	14.5±2.2 (7.2; 27.3)	10.5±1.4 (4.6; 17.7)	73.6±24.4 (8.7; 233.8)
Subalpine fir	133	17.9±0.9 (2.1; 44.4)	12.5±0.6 (2.2; 27.9)	149.2±16.0 (1.7; 1085.2)
Trembling aspen	799	17.7±0.3 (0.7; 47.2)	15.8±0.2 (1.8; 28.3)	161.1±7.0 (0.1; 1081.5)
Western hemlock	48	16.3±1.2 (3.1; 42.4)	12.3±1.0 (3.5; 28.3)	113.8±22.9 (2.5; 796.8)
Western redcedar	47	19.0±1.6 (5.6; 54.2)	12.4±0.9 (3.8; 32.4)	130.1±29.0 (5.8; 1153.9)
White birch	629	16.4±0.3 (1.5; 43.6)	13.3±0.2 (2.6; 23.9)	149.9±6.9 (0.4; 1020.8)
White spruce	931	16.8±0.3 (1.8; 57.6)	12.9±0.2 (1.1; 37.5)	133.1±6.3 (0.4; 1577.7)

Note: Each mean (±SE) has been calculated from the number of trees. Values in parentheses indicate the range.