TFL 23

Analysis of destructive sampling data

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EXECUTIVE SUMMARY

In March 2007, the "Vegetation Resources Inventory Project Implementation Plan (VPIP) for Tree Farm License (TFL) 23 Net Volume Adjustment Factor (NVAF) Sampling"[1] proposed the collection of 130 trees for destructive sampling for the purpose of calculating net volume adjustment factors (NVAF). The hemlock stratum in TFL 23 was purposefully oversampled so that concerns regarding underestimation of unmerchantable volume in this high decay species could be examined in more detail. The NVAF sampling was completed in 2008.

The objective of this analysis was to:

- Provide NVAF values that can be applied to VRI Phase 2 ground sample volume compilation as part of a VRI statistical adjustment in TFL 23;
- Characterize the taper equation and decay estimation bias;
- Use the destructively sampled tree data to analyze bias trends in decay and taper estimates for hemlock; and
- Examine the merchantable volume measurement and its relationship to estimates of loss (decay and waste) and log grades.

NVAF values were computed for eight strata for adjustment of VRI Phase 2 ground samples compiled using BEC-based taper equations and net factoring for the estimation of decay and waste 2. These NVAFs and associated sampling errors are shown in the table below.

NVAF values (for CU net DW2 volume) and 95% sampling errors by stratum for TFL 23.

NVAF stratum	***n* (number of NVAF sample trees)**	***NVAF value* (CU net DW2 volume)**	***Sampling error %* (at 95% confidence level)**
Balsam	9	0.914	2.7%
Cedar	16	0.970	10.3%
Douglas-fir	12	0.967	8.0%
Hemlock	45	0.972	13.6%
Spruce	10	0.969	4.9%
Other species	8	0.995	11.9%
Immature (all species)	20	0.942	9.3%
Dead (all species)	10	0.930	24.6%

The NVAF values in all strata indicate that the BEC-based taper equations in combination with VRI net factoring overestimate volume in TFL 23. However the relatively high sampling errors for the hemlock, "other species", and cedar strata reflect a higher level of uncertainty around the NVAF values in these strata. Additional sampling in these strata could improve the confidence in the NVAF estimates.

Further analysis of the NVAF data indicated that the VRI net factoring process underestimated decay and waste in all strata. This underestimation bias was greatest for dead trees, followed by

[1] Prepared by A.Y. Omule, Rural Forestry International Ltd, March 2007. 21p.

live cedar and hemlock, two species with typically high decay. The taper equation bias varied considerably among the strata and ranged from a 6.4% average volume underestimation for cedar to a 6.8% average volume overestimation for balsam.

For live mature hemlock, BEC-based taper equations and net factoring overestimated CU volume net decay and waste by about 3%. The taper equation on its own, however, underestimated volume in hemlock trees by about 4.5%. Net factoring, on the other hand, overestimated volume in hemlock by about 7.3%. In other words, net factoring underestimated the volume of decay and waste in hemlock by 7.3%.

The bias trends for hemlock associated with net factoring for decay and waste estimation were very different compared with the bias trends associated with the use of FIZ-based loss factors. Whereas net factoring *under*estimated decay and waste in hemlock in TFL 23, FIZ-based loss factors *over*estimated decay and waste in hemlock, by about 20% on average.

Merchantable or "sawable" volume is not a standard measurement in VRI ground samples. Currently, it is only indirectly represented by log grade predictions. The additional data on unmerchantable volume collected for the destructively sampled NVAF trees in TFL 23 were examined to determine the potential for improving estimates of sawable volume.

An example of potential NVAFs for adjusting estimates of CU net DW2 volume for merchantability or sawability were developed and are shown below:

NVAFs to produce estimates of sawable volume from estimates of CU net DW2 volume.
(i.e. NVAFs to correct for bias in taper, decay and waste, and to adjust for sawability).

		Sawable NVAFs ***i.e. adjustment to produce net CU "sawable" or "merchantable" (with 95% sampling error)***	
NVAF stratum	***n* *(number of sample trees)***	*Applied to CU net DW2 volume estimates using BEC-based taper and net factoring*	*Applied to CU net DW2 volume estimates using Rev Br taper and FIZ loss factors*
Balsam	9	0.886 (4.4%)	1.076 (4.5%)
Cedar	16	0.751 (17.8%)	1.101 (20.4%)
Douglas-fir	12	0.955 (10.2%)	1.053 (11.1%)
Hemlock	45	0.826 (12.3%)	1.026 (12.2%)
Spruce	10	0.922 (12.6%)	0.879 (18.1%)
Other Species	8	0.989 (13.9%)	1.048 (18.0%)
Immature	20	0.915 (10.3%)	0.985 (6.4%)
Dead	10	0.627 (29.0%)	1.151 (16.6%)

With the exception of the live mature balsam stratum, the sampling errors for the "sawable" NVAF ratios were well over 10%. This high degree of variability calls into question the reliability of this NVAF-type adjustment to produce an estimate of sawable volume. However, increasing the number of sample trees could reduce the uncertainty around the sawable NVAF values and make this approach more credible.

Using the unmerchantable volume data from destructive sampling to gain confidence in the estimated log grade distribution holds promise but requires further development.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the considerable support, guidance and project direction provided by Will Smith, Volume & Decay Officer, Forest Analysis and Inventory Branch, Ministry of Forests and Range. We also acknowledge the support of Frances Swan, FIA Coordinator, International Forest Products, Nakusp and the suggestions of Chris Mulvihill, Inventory Forester, Ministry of Forests and Range, Nelson.

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1. INTRODUCTION

1.1 Background

In March 2007, the "Vegetation Resources Inventory Project Implementation Plan (VPIP) for Tree Farm License (TFL) 23 Net Volume Adjustment Factor (NVAF) Sampling"[2] proposed the collection of 130 trees for destructive sampling for the purpose of calculating net volume adjustment factors (NVAF). The hemlock stratum in TFL 23 was purposefully oversampled so that concerns regarding underestimation of unmerchantable volume in this high decay species could be examined in more detail. The NVAF sampling for this project was completed in 2008.

In the Vegetation Resources Inventory (VRI), the NVAF is used to correct for bias in the Phase 2 compiled volumes that is associated with hidden decay and the taper functions. The NVAF is computed based on the relationship between the actual volume (from the destructively sampled trees) and the Phase 2 ground sample estimation of close utilization volume net decay and waste (from the VRI compiler and call grading/net factoring information collected in the field).

The destructive sampling data collected in the NVAF sampling can also be used to assess potential bias in taper equations other than the standard biogeoclimatic zone (BEC)-based equations used in VRI volume compilation. For example, the data can be used to assess potential bias in the FIZ-based taper equations used by the Ministry of Forests and Range (MFR) Revenue Branch in the compilation of valuation cruising data. Similarly, the NVAF data can also be used to assess potential bias associated with alternative decay estimation systems (e.g. the 1976 FIZ-based tabular loss factor tables). As the VRI and NVAF have been implemented around the province, the NVAF destructive sampling has shown that there may be considerable bias associated with the taper equations and the old FIZ-based loss factors. The precise nature and extent of this bias varies across the province.

The current VRI system does not provide estimates of true merchantable or sawable volume; instead the loss factors and the net factoring process provide a measure of total sound wood fibre. VRI and NVAF only indirectly measure merchantable volume, via log grade predictions. However, in 2007, a new measurement of unmerchantable volume, designed to represent sawability and based on scaling conventions, was introduced into the NVAF sampling procedures in an effort to provide information that could be used to correct the volume estimates for unmerchantability.

In TFL 23 there were concerns that merchantable volume in hemlock, a high decay species, was being overestimated. To enable a more thorough examination of this concern, the number of trees in the hemlock stratum was increased in the sample design. Specific comments on bias trends in the volume estimation for this species will be highlighted throughout this report.

[2] Prepared by A.Y. Omule, Rural Forestry International Ltd, March 2007. 21p.

1.2 Scope and Objectives

The objective of this analysis was to use the destructive sampling data gathered for NVAF to analyze and characterize the bias associated with alternative estimates of taper and loss in TFL 23. A new measurement of unmerchantable volume[3] will also be examined in this analysis to determine its potential for providing better estimates of merchantable or sawable volume.

Specifically, this analysis will:

- Provide NVAF values that can be applied to VRI Phase 2 ground sample volume compilation as part of a VRI statistical adjustment in TFL 23;
- Characterize the taper equation and decay estimation bias;
- Use the destructively sampled tree data to analyze bias trends in decay and taper estimates for hemlock; and
- Examine the merchantable volume measurement and its relationship to estimates of loss (decay and waste) and log grades.

2. METHODS

2.1 NVAF sample tree distribution

The NVAF sample design was specified in the VPIP[4] and called for the selection of 130 trees (120 live trees and 10 dead trees) for destructive sampling. Of the live trees, 20 were immature (from polygons < 80 years old), 45 were mature western hemlock (Hw) and 55 were other mature species. The oversampling of mature western hemlock trees was specified so that a more precise assessment of accuracy of the taper equation and decay estimation for this species could be carried out. Note that sampling weights are computed and applied for all of the NVAF computations.

The distribution of the NVAF samples trees is shown in Table 1 below:

Table 1: Distribution of NVAF sample trees by stratum.

Live, Mature (n=100)						*Live, Immature*	*Dead*
Balsam	Cedar	Douglas-fir	Hemlock	Spruce	Other species[5]		
9	16	12	45	10	8	20	10

[3] This measurement is the area of the unmerchantable wood (trim and grade allowance) and the associated defects, coalesced into one ellipse. To facilitate data collection, this value is captured as “stain” using the DVHandheld software.

[4] “Vegetation Resources Inventory Project Implementation Plan for Tree Farm License (TFL) 23 Net Volume Adjustment Factor (NVAF) Sampling”, A.Y. Omule, Rural Forestry International Ltd, March 2007. 21p.

[5] The “Live, Mature, Other species” stratum was comprised of 3 larch, 3 lodgepole pine and 2 white pine trees.

2.2 Volumes used in the analysis

A number of volumes were computed for this analysis and referred to throughout this report. These volumes are defined in the table below for reference. There are two main sets of volumes:

1. Actual volumes obtained from the destructive sampling data. Neither taper equations nor decay estimation systems are required since the soundwood and decay volumes are measured directly.
2. Compiled volumes based on the tree data collected by the cruisers. These volumes are referred to as the "cruiser" volumes or the "estimated" volumes. For these volumes, taper equations are used to estimate the gross whole stem volume of the tree and are also used to obtain the volume of the tree net of the top and stump at a given utilization. Decay estimation systems are then used to estimate the percentage of decay and unavoidable waste[6] (DW2) a log or tree basis.

Table 2: Description of volumes used in the analysis (note: all volumes were for trees of 12.5cm+ in dbh).

Actual volumes from destructive sampling data			
Actual CU volume[7]	Volume inside bark net top and stump at close utilization (CU).		
Actual CU net DW2	Volume net top and stump at close utilization (CU) and net decay and unavoidable waste (i.e. waste 2).		
Actual CU net unmerchantable volume	Volume net top and stump at close utilization (CU) and net of unmerchantable volume (i.e. net of decay, trim, grade reduction and unavoidable waste). This is also referred to as "sawable" or "merchantable" volume.		
Estimated volumes from compiler			
		Compiler taper equation options	*Compiler decay estimation options*
Estimated CU volume	Volume inside bark net top and stump at close utilization (CU).	• BEC-based • FIZ-based • Revenue Branch FIZ-based	na
Estimated CU net DW2	Volume net top and stump at close utilization (CU) and net decay and unavoidable waste (i.e. waste 2).	• BEC-based • FIZ-based • Revenue Branch FIZ-based	• Net factoring • FIZ-based loss factors[8]

[6] Unavoidable waste (or waste 2) is defined on a log basis as follows: if the sound wood is less than 50% of the whole stem volume then any remaining volume in the log is considered waste.

[7] Historically, this volume (i.e. tree volume net of top and stump) was often referred to as "merchantable" volume. However, since "merchantable" is a misnomer for this volume and therefore the term "close utilization" (CU) volume is used in this report. Note that CU volume specifically refers to the in side bark volume of a tree between a 30 cm high stump and a 10cm diameter top.

[8] These refer to the 1976 tabular FIZ-based loss factors.

2.3 NVAF computation

The actual volume of each NVAF sample tree was based on the destructive sampling data. The estimated volume of each sample tree was obtained using the VRI compiler (using the BEC-based taper functions and net factoring for decay). The NVAF value was then computed as the ratio of weighted mean actual sample tree volume over the weighted mean estimated sample tree volume, where both volumes were net top and stump (at close utilization) and net decay and waste[9]. In the VRI, these NVAF values can be used to adjust the net factored CU volume for the VRI ground samples and hence correct for potential bias in taper and for hidden decay in an adjusted inventory.

NVAF values are computed on a stratum basis. A separate NVAF value was computed for the dead trees and also for the live immature trees. Alternative stratification of the trees species among the mature live NVAF sample trees was investigated. Hemlock trees were kept in a separate stratum since this species was to be a focus of the analysis. Sample sizes for balsam, cedar, Douglas-fir and spruce were each sufficient for these species to be maintained as independent strata. The remaining mature live trees were grouped into an “other species” stratum.

Within each NVAF stratum, individual tree weights representing the sample tree selection probability were computed using a model-based approach[10], in accordance with current MFR standards. These trees weights were used in the computation of the NVAF, which was a ratio of weighted means.

2.4 Assessment of taper and decay system bias

In addition to the standard volume compilation used for the computation of NVAF values, additional volumes were produced to facilitate further assessment and comparison of the individual taper and decay estimation systems, using the actual volumes from the destructively sampled trees as a base for the comparison.

Volume estimates using BEC-based taper, FIZ-based taper, Revenue Branch FIZ-based taper, FIZ-based tabular loss factors, net factoring and combinations thereof were compiled. Many of these alternative taper and loss systems have been used to estimate volume historically and hence the NVAFs based on these volumes can be used for various purposes. For example[11]:

- An NVAF with compiled volumes using BEC-based taper and Net Factoring would be used to adjust current VRI ground sample volumes;
- An NVAF with compiled volumes using FIZ-based taper and Net Factoring for decay could have been used to adjust the volumes cited in the 2002 Sterling Wood VRI Adjustment Report;
- An NVAF with compiled volumes using FIZ-based taper and FIZ-based Loss Factors can provide sensitivities around the 90's inventory audit samples;
- An NVAF with compiled volumes using Revenue Branch FIZ-based taper and FIZ-based Loss Factors can provide sensitivities around the accuracy of appraisal cruise volumes[12].

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[9] CU volume at 12.5cm+ dbh net decay and waste 2.

[10] “Net Volume Adjustment Factor Sampling Procedures and Standards version 4.3”, Forest Analysis & Inventory Branch, Ministry of Forests & Range, May, 2008.

[11] Will Smith, Volume & Decay Officer, FAIB, MFR. Pers. comm.

[12] NVAF values to correct the bias for these alternative volumes, are provided in Appendix B.

In addition to computing NVAFs, comprehensive graphical analysis was also used to compare the taper and loss estimation alternatives.

2.5 Unmerchantable volume

Net factoring and loss factors on their own or used in conjunction with NVAF to correct for decay estimation bias, may overstate actual "sawable" or "merchantable" volume. In an effort to examine the difference between traditional estimates of decay and waste and the broader concept of "unmerchantable" volume, new destructive sampling data collection procedures were recently implemented. The following description of the concept and procedure for measuring merchantable or "sawable" volume in NVAF destructive samples is abstracted from a paper written by Will Smith, Volume and Decay Officer, FAIB, MFR[13]. Project specifications for collecting data to measure unmerchantable volume are provided in Appendix A.

> "This is a new concept for VRI and NVAF because merchantable volume is only indirectly measured in VRI ground samples via log grade predictions and is not a standard measurement in NVAF nor its predecessor, the historic decay sampling. NVAF sampling is a classic strategic inventory tool in that its primary objective is to provide a stable measurement of total sound wood fibre and not one for an ever shifting definition of merchantability that is dependent on current market conditions. However, the interest around shelf life due to the MPB infestation and the collapse of the pulp market in the northwest has provided a renewed interest in merchantable wood and the testing of a possible new tool in the VRI toolkit. The results must be cautiously interpreted due to a small sample size and this measurement of unmerchantable wood represents an underestimate of mill recovery as it was captured for 2 meter long logs from the destructive sample in the absence of yarding, loading, hauling and milling."

Pilot NVAF values were developed using this new measure of "merchantable" or "sawable" volume from the destructive samples. In addition, the data on unmerchantable volume for each log was used to reassess the grades[14] assigned to each log by the NVAF cruiser. The analysis provided a preliminary examination of the shift in the log grades that was observed when this supplemental information on unmerchantable volume was applied in the grade reassessment.

3. RESULTS AND DISCUSSION

3.1 NVAF analysis

NVAF values were computed so that VRI Phase II ground volumes can be corrected for potential bias in taper associated with the BEC-based taper equations and hidden decay associated with the net factoring estimates of decay[15]. The results by stratum are shown in Table 3 that follows.

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[13] "Merritt TSA NVAF Analysis", Will Smith, Volume & Decay Sampling Officer, Forest Analysis and Inventory Branch, Ministry of Forests & Range. 2008. 10pp.

[14] Grades were reassessed on a log-by-log basis by Will Smith, by incorporating the information on actual measured "unmerchantable" volume into the grade decision.

[15] Other NVAF values, that could be used to correct for bias associated with other volume estimates such as those outlined in section 2.4 (e.g. volumes generated from Revenue Branch FIZ-based taper equations and FIZ-based loss factors), were also computed. These NVAF values are provided in Appendix B.

The NVAF values in Table 3 indicate that the VRI compiler overestimates[16], on average, CU volume (i.e. net top and stump) net decay and unavoidable waste. The magnitude of the volume overestimation ranges from nearly 9% for live mature balsam to less than 1% for mature species other than balsam, cedar, spruce and hemlock (i.e. species such as pine and larch). Note that the application of these NVAF values in the VRI compiler will correct for this bias. Scatterplots showing the NVAF relationships in Table 3 are provided in Appendix C.

The sampling errors associated with the NVAF values in the cedar and "other species" strata are relatively high which reduces the confidence in these NVAF values. Additional sampling could improve the level of certainty associated with the NVAF in these strata. The sampling error in the hemlock stratum is quite high despite the fact that this stratum included 45 sample trees. Given the concerns around volume overestimation in hemlock, further sampling may be warranted in an effort to improve the confidence in the hemlock NVAF value.

Table 3: NVAF values (for CU net DW2 volume) and 95% sampling errors by NVAF stratum for TFL 23. Note: NVAF is ratio of *weighted* average actual CU net DW2 volume / *weighted* average estimated CU net DW2 volume where the estimated volumes are based on ***BEC taper equations*** and ***VRI net factoring***.

NVAF stratum	***n* (number of NVAF sample trees)**	***NVAF value* (CU net DW2 volume)**	***Sampling error % (at 95% confidence level)***
Balsam	9	0.914	2.7%
Cedar	16	0.970	10.3%
Douglas-fir	12	0.967	8.0%
Hemlock	45	0.972	13.6%
Spruce	10	0.969	4.9%
Other species	8	0.995	11.9%
Immature (all species)	20	0.942	9.3%
Dead (all species)	10	0.930	24.6%

3.1.1 Taper equation bias

The bias implied by the NVAF values in Table 3 was further analyzed to determine the relative contribution of the bias from both the taper equation and from the net factoring estimates of decay. For taper bias, this was accomplished by computing a ratio of weighted actual CU volume and weighted estimated CU volume. As a result, the impact of decay estimation was excluded. The results of this evaluation are shown in Table 4.

[16] An NVAF value of 1.0 would represent no average bias. NVAF values less than 1.0 represent volume overestimations and NVAF values greater than 1.0 represent volume underestimations. For example, an NVAF value of 0.914 for live balsam trees can be interpreted as an 8.6% (~9%) volume *over*estimation for this species grouping.

Table 4: Ratios reflecting bias in BEC-based taper equations (actual CU volume/estimated CU volume) and 95% sampling errors by NVAF stratum for TFL 23.

NVAF stratum	*n (number of sample trees)*	*Ratio of weighted actual CU/ wt'd estimated CU*	*Sampling error % (at 95% confidence level)*
Balsam	9	0.938	2.8%
Cedar	16	1.064	7.1%
Douglas-fir	12	0.973	7.7%
Hemlock	45	1.045	3.4%
Spruce	10	0.989	6.3%
Other Species	8	1.019	8.9%
Immature (all species)	20	0.953	7.5%
Dead (all species)	10	1.033	14.5%

Table 4 indicates that bias associated with the BEC-based taper equations varies among the species strata. For example, the ratio of 1.064 for cedar indicates that the taper equations *under*estimate the CU volume for cedar by 6.4%, on average, whereas the ratio of 0.938 for balsam indicates that the taper equations *over*estimate CU volume for this species by 6.2%. The taper biases in other strata fall between these two values. For species like cedar and hemlock, the sampling errors associated with the taper ratios were considerably lower than that for the NVAF ratios in Table 3. This may indicate that although the taper bias for these two species is relatively consistent, there is significant variability associated with decay estimation for cedar and hemlock.

3.1.2 Decay estimation bias

The difference between the ratios in Table 3 and Table 4 (i.e. the difference between the CU volume ratios and the net CU net DW2 volume ratios) can be interpreted as the error or bias associated with the estimation of decay and waste 2 based on the net factoring process. A positive error or bias indicates that net factoring is *under*estimating soundwood volume whereas a negative error or bias indicates that net factoring is *over*estimating soundwood volume. The results shown in Table 5 indicate that net factoring consistently *overestimates soundwood volume* in all species strata in TFL 23. Note that this in turn indicates that net factoring is *underestimating decay and waste* in all species strata in this management unit.

Table 5: Percentage bias in CU net DW2 volume associated with net factoring estimates of decay and waste.

NVAF stratum	*n (number of sample trees)*	*% bias in CU net DW2 volume associated with net factoring*
Balsam	9	-2.4%
Cedar	16	-9.4%
Douglas-fir	12	-0.6%
Hemlock	45	-7.3%
Spruce	10	-2.0%
Other Species	8	-2.4%
Immature (all species)	20	-1.1%
Dead (all species)	10	-10.3%

Among the live species strata, the decay and waste underestimation associated with net factoring is greatest in cedar (9.4%) and hemlock (7.3%). For other live species, the decay underestimation for net factoring is less than 2.5%.

The high percentage of error associated with the estimate of decay and waste for cedar is not unexpected since there is typically significant hidden decay in this species. Although net factoring overestimates soundwood volume in cedar, the taper equations for this species underestimate volume (see Table 4), resulting in an NVAF value of 0.970, higher than is usually seen for this species.

3.2 Comparison of bias associated with taper equation alternatives

Although BEC-based taper equations are the current Forest Analysis and Inventory Branch (FAIB) standard for volume compilation, FIZ-based taper equations are commonly used in Revenue Branch cruise compilations. For TFL 23, Revenue Branch uses a modified set of FIZ-based taper equations[17] (that differ slightly from the standard FIZ-based equation for cedar and hemlock) for valuation cruise compilation.

The destructively sampled data was used to compare taper bias among these three systems:

- BEC-based taper equations
- FIZ-based taper equations
- Revenue Branch modified FIZ-based taper equations

Ratios summarizing and comparing the taper bias by stratum are shown in Table 6. Note that the values shown in Table 6 for BEC-based taper equations are identical to those shown in Table 4.

Table 6: Ratios reflecting bias in BEC-based, FIZ-based and Revenue Branch FIZ-based taper equations for CU volume, by stratum[18].

Stratum	*n (number of sample trees)*	***Ratio of weighted actual CU vol/ wt'd estimated CU vol (95% sampling error)***		
		BEC-based taper	*FIZ-based taper*	*Revenue Branch FIZ-based taper*
Balsam	9	0.938 (2.8%)	0.882 (4.5%)	0.882 (4.5%)
Cedar	16	1.064 (7.1%)	1.002 (6.6%)	1.124 (6.2%)
Douglas-fir	12	0.973 (7.7%)	1.028 (8.0%)	1.028 (8.0%)
Hemlock	45	1.045 (3.4%)	0.907 (2.7%)	1.036 (2.7%)
Spruce	10	0.989 (6.3%)	0.947 (4.6%)	0.947 (4.6%)
Other Species	8	1.019 (8.9%)	1.026 (11.3%)	1.026 (11.3%)
Immature (all species)	20	0.953 (7.5%)	0.976 (5.9%)	0.991 (5.7%)
Dead (all species)	10	1.033 (14.5%)	0.922 (20.1%)	0.921 (20.2%)

[17] A modified equation was developed for cedar and hemlock in the Interior Wet Belt.

[18] Note that differences among taper equations directly impact the CU as well as the whole stem volume (WSV), since taper equations affect the estimate of merchantable height and top diameter. Hence the assessment of taper equation bias is based on CU volume.

The Revenue Branch modification to the FIZ-based taper equations affected only cedar and hemlock trees. In TFL 23, this modification reduced the taper bias for hemlock but the modification appeared to exacerbate the taper bias for cedar trees.

The data in Table 6 suggests that BEC-based taper equations have less error than Revenue Branch FIZ-based taper equations in all strata except for immature live trees (where the BEC-based taper volume estimates are about 4% worse) and hemlock (marginally worse).

Trends in bias, particularly as related to certain tree characteristics, are often easier to discern in plots of the data. The distribution of the sample data and the influence of potential outlying samples are more readily examined graphically. As a result, trends in taper equation bias as a function of a variety of variables were produced and are shown in Figures 1 to 12 that follow[19].

In each of these graphs, the bias associated with a taper equation estimate of CU volume is represented by the ratio (computed for each individual sample) of the actual CU volume (measured from the destructively sampled tree) over the CU volume estimated by the taper equation. If the taper estimate of CU volume for the sample tree is very close to the actual estimate, the ratio will be close to 1.0 i.e. no bias (shown as the horizontal line on the graph). When the taper equation *under*estimates the actual volume, the ratio will be greater than 1.0 (point will be above the horizontal line). Similarly, when the taper equation *over*estimates the actual volume, the ratio will be less than 1.0 (and the point will be below the horizontal line). The graphs are organized in threes so that trends for the BEC-based taper equation, the FIZ-based taper equation and the Revenue Branch FIZ-based taper equation can be observed side-by-side.

Figures 1 to 3 show the taper equation bias related to tree dbh. Note that points below the line (negative bias) indicate that the taper equation overestimates volume. From these graphs it appears that the FIZ-based taper equation tends to overestimate volume for trees with larger dbh[20].

The trends in taper equation bias were also examined as a function of other variables such as tree age (Figures 4 to 6) and height (Figures 7 to 9). In relation to these variables the patterns in bias were less distinct. However, in general, the BEC-based taper equation appears to compare more favorably than the FIZ-based taper alternatives.

The taper equation bias was also plotted by stratum[21] (Figures 10 to 12) to illustrate the bias relationships among the strata and the variability of this bias within each stratum. On a stratum basis,

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[19] The data points in these graphs do not reflect the model-based weights associated with each sample tree. Samples must be weighted appropriately when computing aggregate values (i.e. means, ratio of means, etc.).

[20] In viewing Figure 2, the data points appear to have a heavier distribution below the horizontal line especially in the region beyond about 75 cm dbh. This indicates a potential trend to overestimate volume in this range of dbh.

[21] Figures 10 to 12 are called *dot density plots*. The species strata are aligned along the x-axis. Each dot of the same colour above a stratum label represents a sample trees within a particular stratum. When more than one sample tree shares a particular bias value (i.e. y-axis value), the dots are "stacked" horizontally to the right. Hence, the dots represent the frequency distribution of costs for each category along the x-axis (with the distribution oriented vertically). This type of graph makes it possible to visually distinguish potential differences among categories of a variable (i.e. among species strata in this case) and provides a good picture of the variability within a stratum as well as the nature of potential outliers.

the BEC-based taper equation appears to generally perform better than the two alternative taper equation alternatives (in terms of average bias and variability of the bias within each stratum).

Plots of taper bias by dbh, age and height were also produced by stratum and are provided in Appendix D.

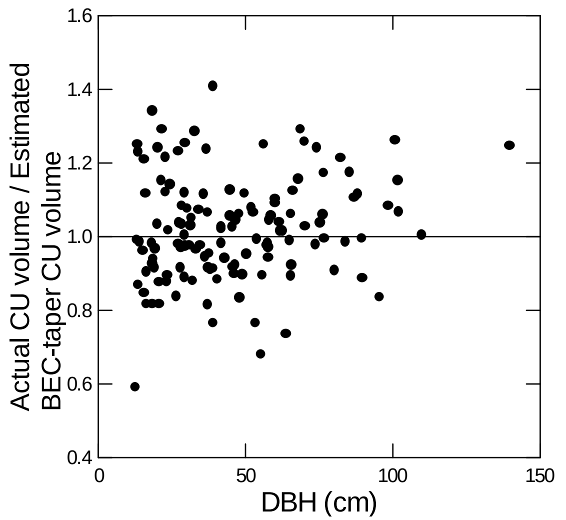

Figure 1: BEC-based taper equation bias for individual samples, as a function of dbh.

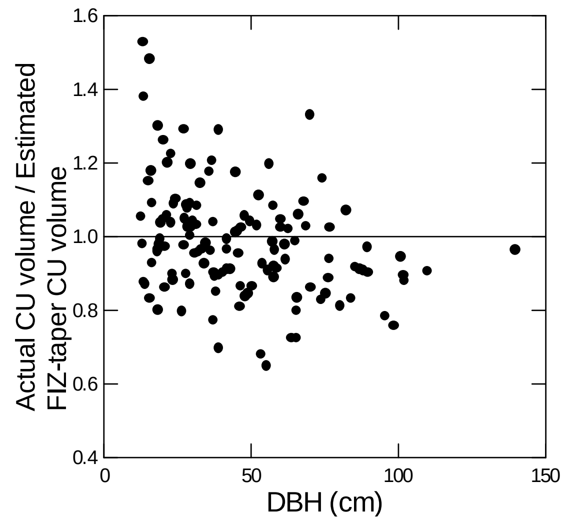

Figure 2: FIZ-based taper equation bias for individual samples, as a function of dbh.

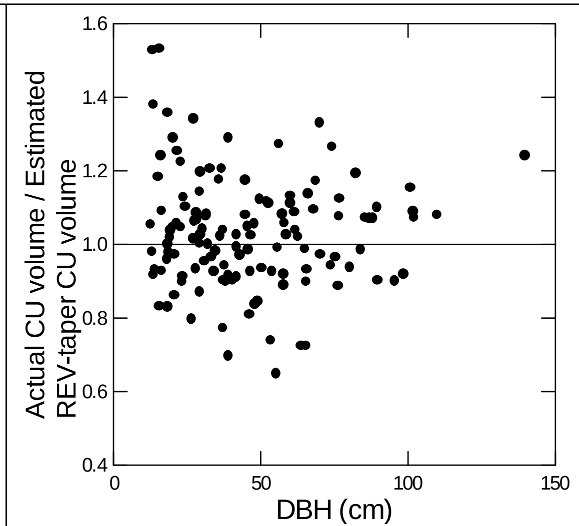

Figure 3: Revenue Br. FIZ-based taper equation bias for individual samples, as a function of dbh.

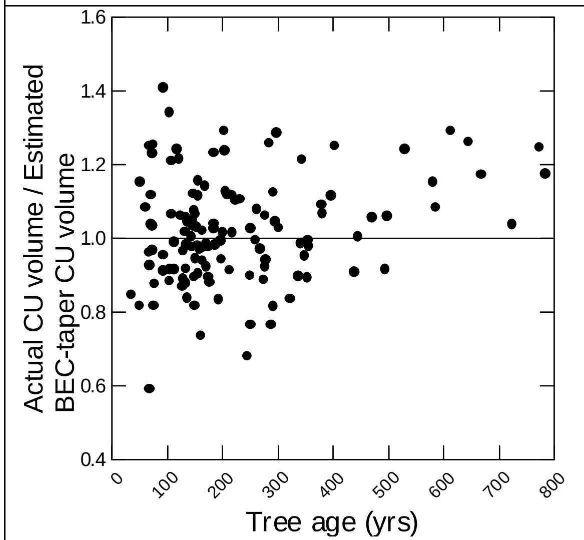

Figure 4: BEC-based taper equation bias for individual samples, as a function of tree age.

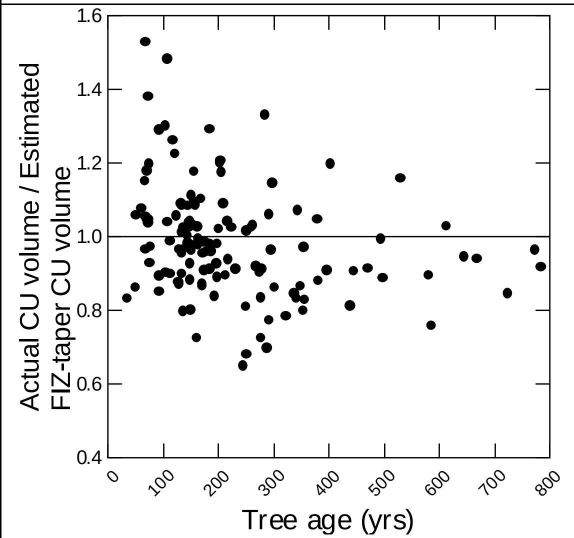

Figure 5: FIZ-based taper equation bias for individual samples, as a function of tree age.

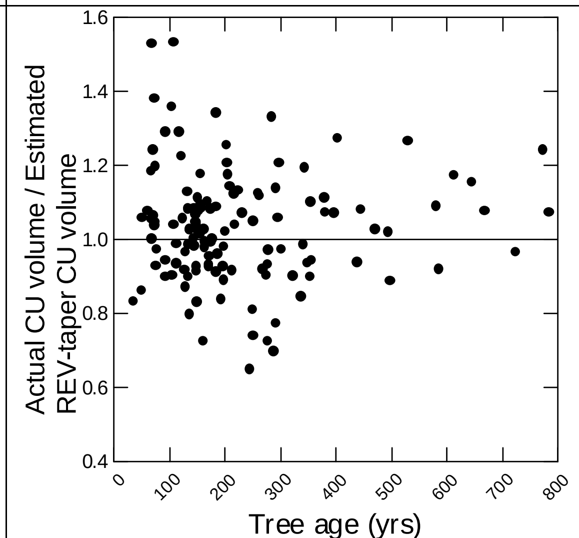

Figure 6: Revenue Branch FIZ-based taper equation bias for individual samples, as a function of tree age.

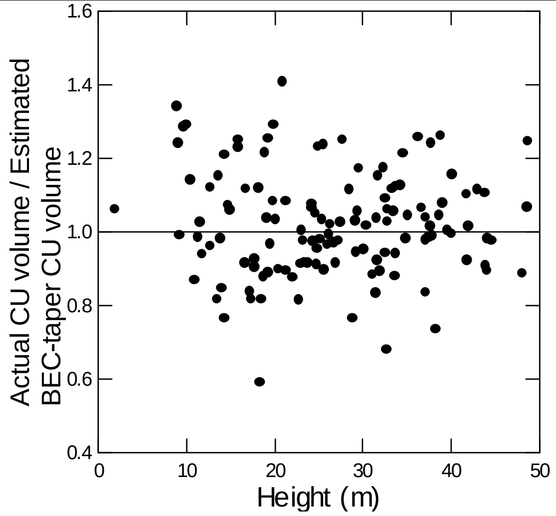

Figure 7: BEC-based taper equation bias for individual samples, as a function of tree height.

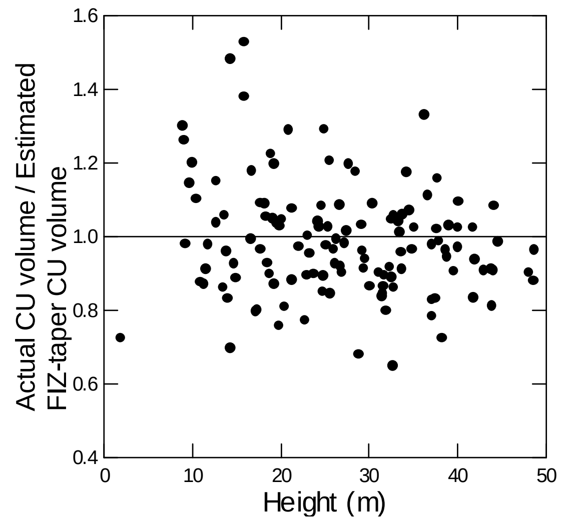

Figure 8: FIZ-based taper equation bias for individual samples, as a function of tree height.

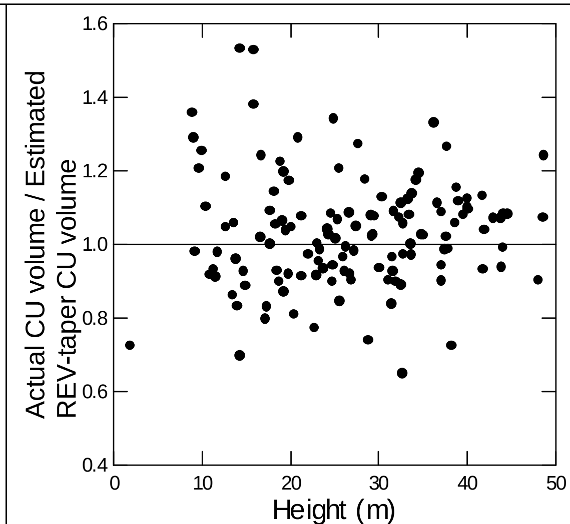

Figure 9: Revenue Branch FIZ-based taper equation bias for individual samples, as a function of tree height.

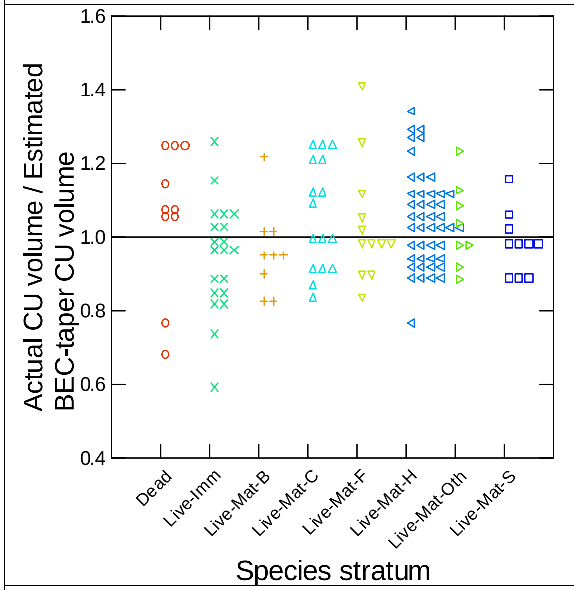

Figure 10: BEC-based taper equation bias for individual samples, by stratum.

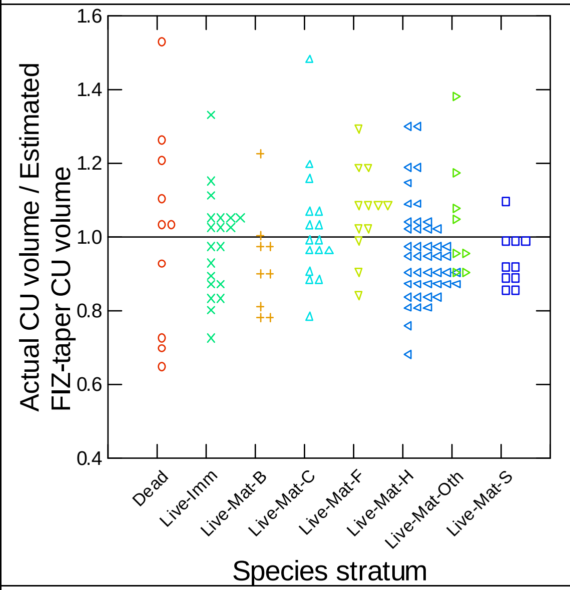

Figure 11: FIZ-based taper equation bias for individual samples, by stratum.

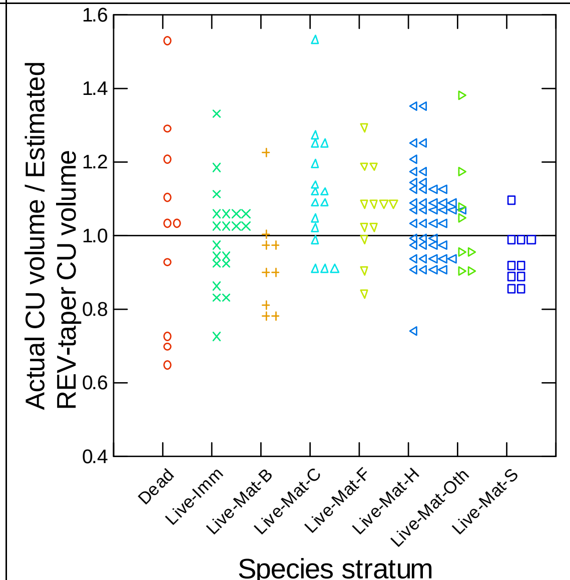

Figure 12: Revenue Br. FIZ-based taper equation bias for individual samples, by stratum.

3.3 Comparison of bias associated with decay and waste for alternative loss estimation systems

The FAIB standard for decay estimation for Phase II ground samples within the Vegetation Resources Inventory is net factoring. Net factoring is a rule-based system where the cruiser estimates the volume of visible decay in a tree. Typically, net factoring is used in conjunction with a net volume adjustment factor (NVAF) to correct for residual bias in the volume estimate due to taper, net factor rule errors and/or hidden decay. Waste is computed based on the estimate of decay. On a log basis, if the sound wood is less than 50% of the whole stem volume then any remaining volume in the log is considered waste. This definition of waste is referred to as "waste 2" or W2.

For valuation cruising, MFR Revenue Branch uses the 1976 FIZ-based tabular loss factors[22] as the standard for decay and waste estimation in cruise volume compilation. These loss factors are dependent on FIZ, species, dbh class and "risk-group"[23]. Loss factor waste is also based on the "waste 2" definition. However, when the tabular loss factors were created in the 1970's, the calculated W2 percentages from the sample trees were plotted and hand-drawn curves on this data were used to determine waste factors by diameter class for the loss factor tables. Hence loss factor waste represents an average waste by diameter class.

More recently, the data used to develop the 1976 tabular loss factors were restratified by BEC (instead of FIZ) and similar loss factors were developed[24]. Although not used by Revenue Branch, these BEC-based loss factors were used in some FAIB compilers prior to adoption of net factoring as the FAIB standard for decay estimation.

To compare estimates from these three loss estimation systems, ratios of weighted actual CU net DW2 volume over weighted estimated CU net DW2 volume were computed. Actual volumes were from the destructively sampled data and the estimates were based on either net factoring or BEC- or FIZ-based tabular loss factors (decay and waste). All three estimates of CU net DW2 volume were computed using BEC-based taper equations so that the impact of loss estimation would be easier to isolate. The results are shown by species in Table 7.

Table 7 shows that for net factoring, soundwood volume is overestimated in all strata. However, both loss factor systems (BEC-based and FIZ-based) underestimate the CU net DW2 volume. Hence, net factoring appears to be *under*estimating loss (decay and waste), and the loss factors (BEC-based and FIZ-based) are *over*estimating decay and waste. This overestimation of decay and waste for loss factors is especially prominent for live cedar and hemlock as well as dead trees.

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[22] As found in the "*Metric Diameter Class Decay, Waste and Breakage Factors*", 1976, Ministry of Forests.

[23] External pathological indicators, maturity, and live/dead place a tree into one of nine "tree classes". Tree classes are grouped into one of three "risk groups" which, in combination with location (FIZ), species and age determines the loss factor table and its associated deductions for decay, waste and breakage.

[24] The BEC-based loss factors were fit using curve fitting routines rather than the hand-fitting procedures used to develop the 1976 FIZ-based loss factors.

Table 7: Percentage bias in CU net DW2 volume associated with alternative estimates of decay and waste.

NVAF stratum	% bias in volume associated with decay & waste estimation[25]			
	***n* (number of sample trees)**	***Net factoring***	***BEC-based loss factors***	***FIZ-based loss factors***
Balsam	9	-2%	8%	24%
Cedar	16	-9%	45%	26%
Douglas-fir	12	-1%	4%	3%
Hemlock	45	-7%	34%	20%
Spruce	10	-2%	3%	3%
Other Species	8	-2%	4%	4%
Immature (all species)	20	-1%	4%	3%
Dead (all species)	10	-10%	40%	64%

To isolate the decay component of the bias (separate from the waste 2 component) on a tree-by-tree basis, the decay percentage estimated by each of net factoring and FIZ-based loss factors[26] were compared with the actual decay percentage found in the trees after destructive sampling. The bias was computed as the actual decay % minus the estimated decay % so that a positive difference represented a decay underestimation and negative difference represented a decay overestimation. Note that a decay *over*estimation will result in a volume *under*estimation. These results were examined graphically in Figures 13 to 15.

Since decay and waste estimates are strongly related to risk group, the bias in decay and waste estimation was examined by risk group[27]. Figures 13 to 15 shows the bias in decay % for net factoring (shown as •'s) and FIZ-based loss factors (shown as ×'s) as a function of tree dbh for each risk group. Figures 16 to 18 provide a similar picture for bias in W2 %.

The majority of the data points (i.e. sample trees) for FIZ-based loss factors lie below the line, indicating that decay % is in general overestimated[28]. This decay overestimation trend is particularly apparent in risk groups 1 and 3. There did not appear to be any clear trends in bias for decay estimation as a function of dbh.

For net factoring, the data points for risk groups 1 generally appear on or above the line (indicating that decay % is either unbiased or underestimated). The pattern of bias for net factoring in risk groups 2 and 3 is less clear, but generally suggest unbiased decay estimation, on average.

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[25] A positive error or bias indicates that the decay & waste estimation system is underestimating sound wood volume whereas a negative error or bias indicates that it is overestimating sound wood volume.

[26] This portion of the analysis focused on net factoring and FIZ-based loss factors since both of these loss systems are in current use (whereas BEC-based loss factors are not).

[27] Risk-groups are defined by the species and age of a tree and the presence and number of visual decay indicators.

[28] The data points in these figures do not reflect the weight associated with the individual samples. Samples must be weighted before any aggregate statistics (i.e. means, ratio of means, etc.) can be computed.

For net factoring, only three trees in the entire sample were estimated to have any waste as calculated using the W2 definition. After decay was calculated for the destructively sampled data, a total of 19 trees (out of 130) were determined to actually have non-zero W2 volume[29]. Destructive sampling indicated that the remainder of the trees (i.e. 111 out of 130 trees) had zero waste. Therefore the waste-related bias for net factoring was relatively low overall.

On the other hand, the FIZ-based tabular loss factor system tends to overestimate waste. The majority of the sample trees (i.e. 95 out of 130 trees) were estimated to have non-zero waste based on the loss factor tabular waste percentages.

A graphical representation of the net factoring and FIZ loss factor results in Table 7, showing bias in decay and waste estimation by stratum, is shown in Appendix E.

[29] Where there was non-zero waste among the destructively sampled trees, the estimation of W2 based on the net factored decay was generally biased. However, because so few trees in the sample had waste, the overall magnitude of this bias was small.

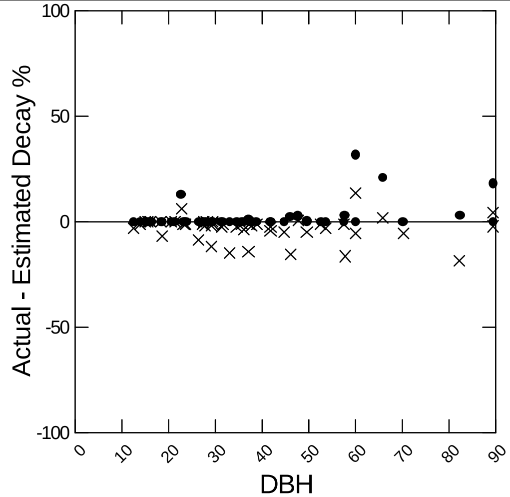

Figure 13: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

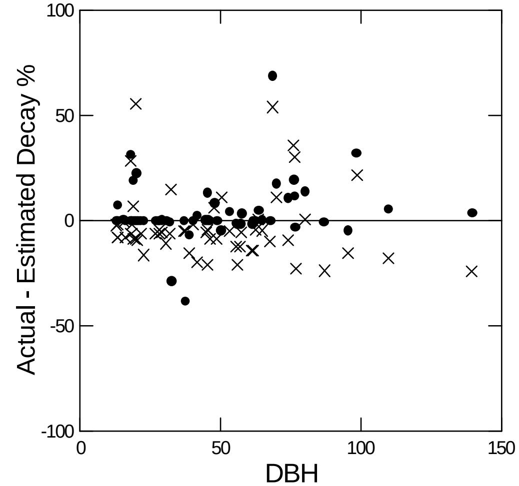

Figure 14: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

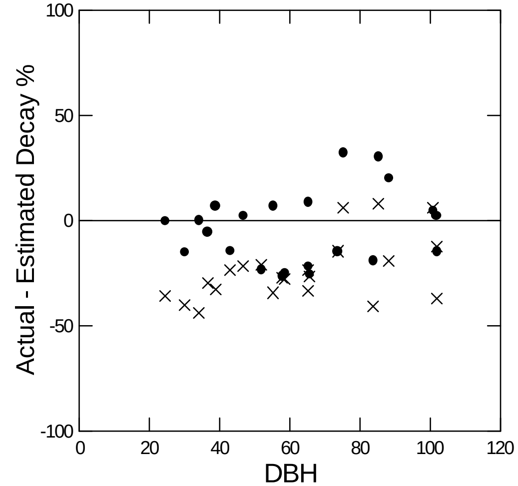

Figure 15: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

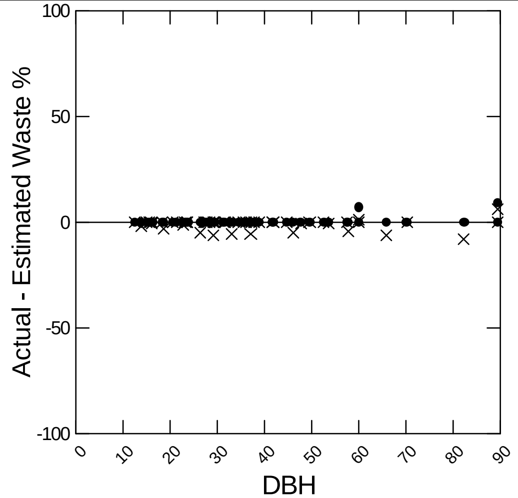

Figure 16: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

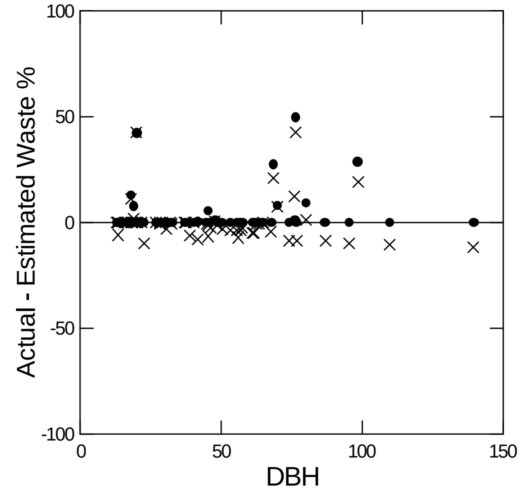

Figure 17: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

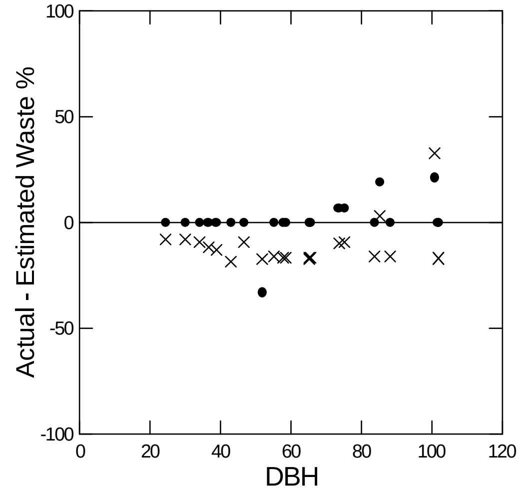

Figure 18: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

3.4 Comments on taper and decay estimation bias for hemlock

For live mature hemlock, BEC-based taper equations and net factoring overestimates CU volume net decay and waste by just under 3%. The NVAF value of 0.972 can be applied in the VRI compiler to correct for this bias. Note that the sampling error for this NVAF is 13.6%. Considering the large number of samples in this stratum, this indicates high relative variability in the relationship between actual and estimated volumes. This is illustrated in Figure 19.

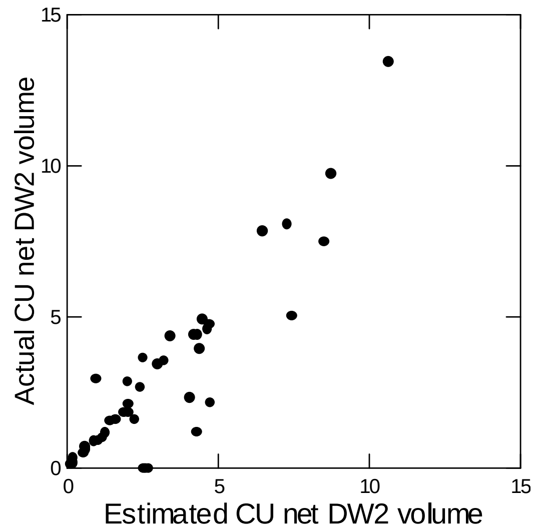

Figure 19: Relationship between actual CU net DW2 volume from destructive sampling and CU net DW2 volume estimated using BEC-based taper equations and net factoring, for hemlock.

Since the NVAF corrects for both taper and decay estimation, these components were examined separately to more precisely identify the source of the bias. The ratio for actual CU volume over estimated CU volume was 1.045 for hemlock indicating that the BEC-based taper equation underestimated volume by about 4.5%. The sampling error for the taper bias was only 3.4%. Figure 20 illustrates the consistency in the taper bias relationship.

The taper bias in hemlock was examined to see if it was related to specific tree characteristics (i.e. tree height, dbh and age). Scatterplots of these relationships are shown in Figures 21 to 23. The taper underestimation bias appeared to be slightly more prominent in shorter trees and in very old trees.

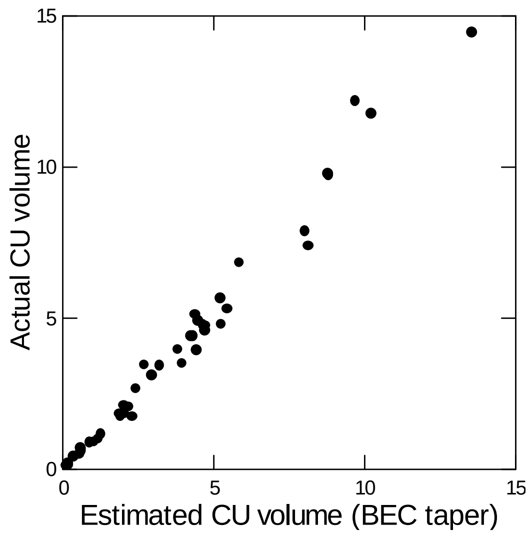

Figure 20: Relationship between actual CU volume from destructive sampling and CU volume estimated using BEC-based taper equations, for hemlock.

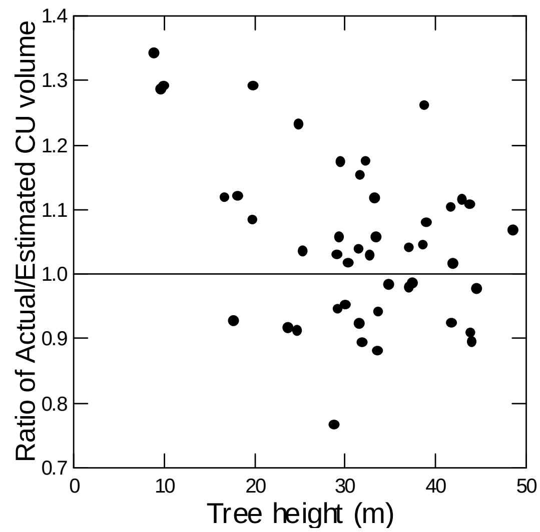

Figure 21: Ratio of actual to estimated CU volume (representing BEC-based taper equation bias) as a function of tree height, for hemlock.

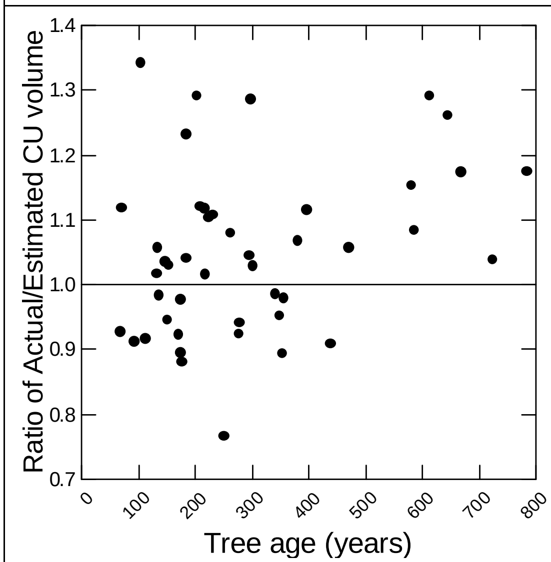

Figure 22: Ratio of actual to estimated CU volume (representing BEC-based taper equation bias) as a function of tree age, for hemlock.

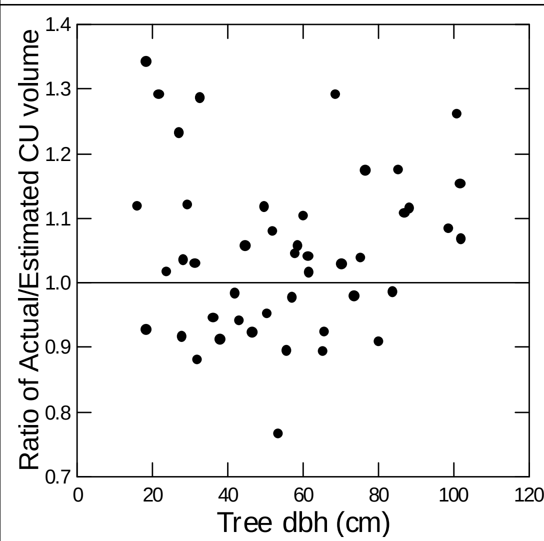

Figure 23: Ratio of actual to estimated CU volume (representing BEC-based taper equation bias) as a function of tree dbh, for hemlock.

BEC-based taper and net factoring resulted in compensatory errors for hemlock (i.e. one was negative and one was positive). Although the BEC-based taper equation *under*estimated volume for hemlock trees by about 4.5%, net factoring resulted in a soundwood volume *over*estimation in hemlock in the magnitude of 7.3%. In other words, net factoring underestimated the volume of decay and waste in hemlock by 7.3%. Together, these two errors resulted in a combined 3.2% volume overestimation for hemlock, where volumes were estimated using BEC-based taper equations and net factoring.

The taper equations used by Revenue Branch to estimate compiled hemlock volumes are FIZ-based and include a modification for cedar and hemlock trees in the Interior Wet Belt. For hemlock trees in TFL 23, use of the Revenue Branch taper equation resulted in slightly less taper bias (3.6% volume underestimation compared with 4.5% volume underestimation using BEC-based taper equations). These results were provided in Table 6.

The bias trends for hemlock associated with net factoring for decay and waste were very different compared with the bias trends associated with the use of FIZ-based loss factors. Whereas net factoring *under*estimated decay and waste, on average, in hemlock in TFL 23, FIZ-based loss factors *over*estimated decay and waste, by about 20% on average. These differences are well illustrated by risk group in Figures 24 and 25.

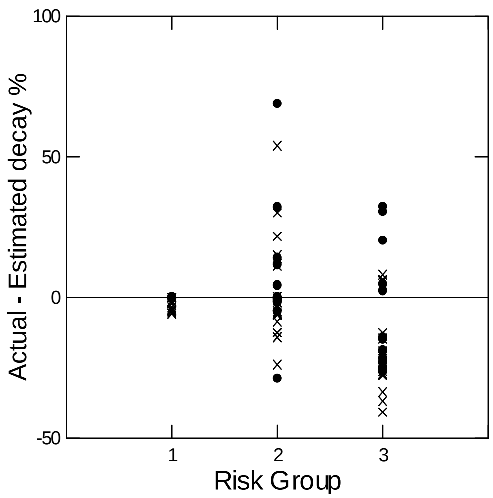

Figure 24: Bias in hemlock estimates of decay % for net factoring and FIZ-based loss factors, by Risk Group. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

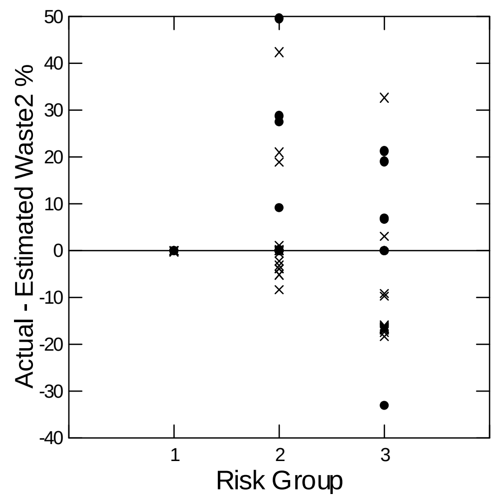

Figure 25: Bias in hemlock estimates of waste2 % for net factoring and FIZ-based loss factors, by Risk Group. NOTE: •'s represent net factoring bias and ×'s represent loss factor bias.

The difference in the bias patterns for net factoring and loss factors is most notable in Risk Groups 1 and 3. In Risk Group 1, the loss factors overestimated decay and waste for 10 out of the 12 trees. Loss factors assigned some level of decay (ranging from 1.4% to 5.9%) for 10 of the 12 live mature hemlock trees in Risk Group 1, whereas actual decay measured from destructive sampling was only present in 5 trees and was less than 0.5% in all cases. Net factoring did not estimate any decay for any of the Risk Group 1 mature hemlock trees. In Risk Group 3, the decay overestimation bias was more significant for loss factors than for net factoring[30]. In Risk Group 2, bias trends in decay estimation were not as easy to discern. However, net factoring was less likely to overestimate waste for hemlock in this risk group compared with loss factors.

[30] The bias for loss factor decay estimation (calculated as the actual decay % minus the loss factor estimated decay %) ranged from an 8.1% decay underestimation to a 40.7% decay overestimation. On average, loss factors overestimated decay in Risk Group 3. For net factoring, the bias ranged from a 32.3% decay underestimation to a 26.4% decay overestimation. Although the net factoring decay estimation bias for hemlock in Risk Group 3 was highly variable, there was no significant average under- or overestimation bias.

All of the 14 mature hemlock trees in Risk Group 3 recorded conks for the standing trees. Graphs showing decay estimation bias for the FIZ-based loss factors in relation to the decay indicators identified on the standing trees, are shown in Appendix F. Similar graphs for net factoring are shown in Appendix G.

For net factoring, the decay estimation bias among the Risk Group 3 trees was not consistent among the indicators. For example, although all of the trees in Risk Group 3 had conk, net factoring both under- and overestimated decay for these trees. The bias associated with the net factored estimates of waste for the Risk Group 3 trees was also particularly variable (see Figure 25).

3.5 Estimating merchantable or "sawable" volume

Merchantable or "sawable" volume is not a standard measurement in VRI ground samples. Currently, it is only indirectly represented by log grade predictions. The additional data on unmerchantable volume collected for the destructively sampled NVAF trees in TFL 23 were examined to determine the potential for improving estimates of sawable volume.

The relationship between unmerchantable volume and the standard measure of decay and waste that is collected for the destructively sampled NVAF trees is shown in Figures 26 to 28, by risk group. In nearly all cases, the measured volume of unmerchantable wood is greater than the measured volume of decay plus waste 2, often by several magnitudes. As the volume of decay and waste increases, these two measures converge.

Although the relationship between *actual* unmerchantable volume and *actual* decay and waste is weak, the relationship between *actual* unmerchantable volume and the standard *estimates* of decay and waste, be it from net factoring or loss factors is marginal (Figures 29 and 30). As a result, the opportunity for developing an unbiased estimate of merchantable volume based on cruise estimates of volume net decay and waste (from either net factoring or loss factors) adjusted with a "sawable" NVAF may be limited.

Table 8 shows the potential NVAF ratios (i.e. "sawable" NVAF's) that could be used to adjust estimated net CU volumes (from either net factoring or loss factors) to obtain estimates of *sawable* volumes. The "sawable" NVAF ratios were computed as ratios of the weighted average actual CU net unmerchantable volume from destructive sampling over the weighted average estimated CU net DW2 volume (from either BEC taper and net factoring or Revenue Branch taper and FIZ-based loss factors).

Table 8: NVAFs to produce estimates of sawable volume from estimates of CU net DW2 volume. (i.e. NVAFs to correct for bias in taper, decay and waste, and to adjust for sawability).

		Sawable NVAFs i.e. adjustment to produce CU net unmerchantable volume (with 95% sampling error)	
NVAF stratum	***n (number of sample trees)***	*Applied to CU net DW2 volume estimates using BEC-based taper and net factoring*	*Applied to CU net DW2 volume estimates using Rev Br taper and FIZ loss factors*
Balsam	9	0.886 (4.4%)	1.076 (4.5%)
Cedar	16	0.751 (17.8%)	1.101 (20.4%)
Douglas-fir	12	0.955 (10.2%)	1.053 (11.1%)
Hemlock	45	0.826 (12.3%)	1.026 (12.2%)
Spruce	10	0.922 (12.6%)	0.879 (18.1%)
Other Species	8	0.989 (13.9%)	1.048 (18.0%)
Immature	20	0.915 (10.3%)	0.985 (6.4%)
Dead	10	0.627 (29.0%)	1.151 (16.6%)

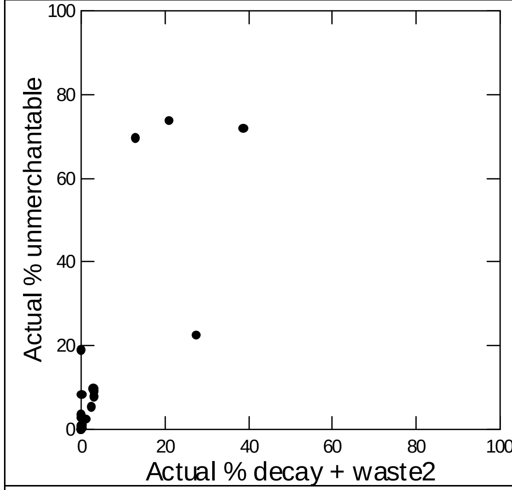

Figure 26: Relationship between actual unmerchantable volume % and actual decay and waste 2 % for Risk Group 1.

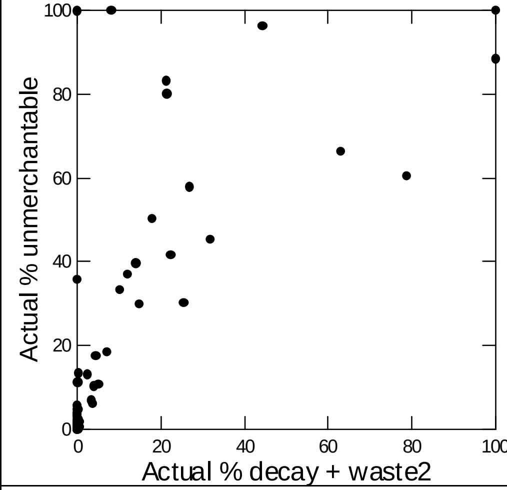

Figure 27: Relationship between actual unmerchantable volume % and actual decay and waste 2 % for Risk Group 2.

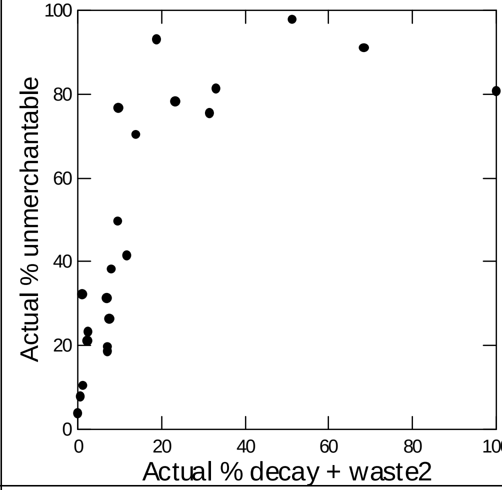

Figure 28: Relationship between actual unmerchantable volume % and actual decay and waste 2 % for Risk Group 3.

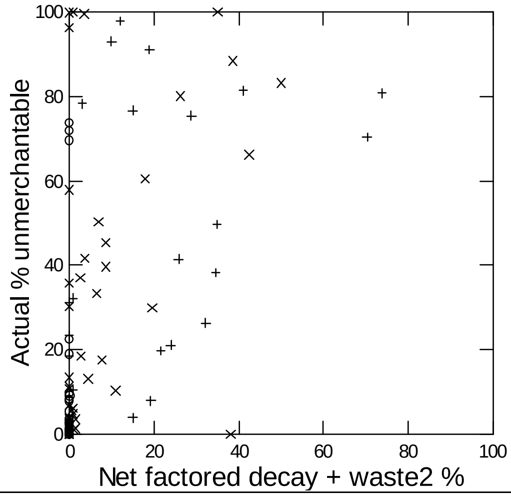

Figure 29: Relationship between actual unmerchantable volume % and net factored estimates of decay and waste 2%. NOTE: o's represent risk group 1 trees; x are risk group 2; + are risk group 3.

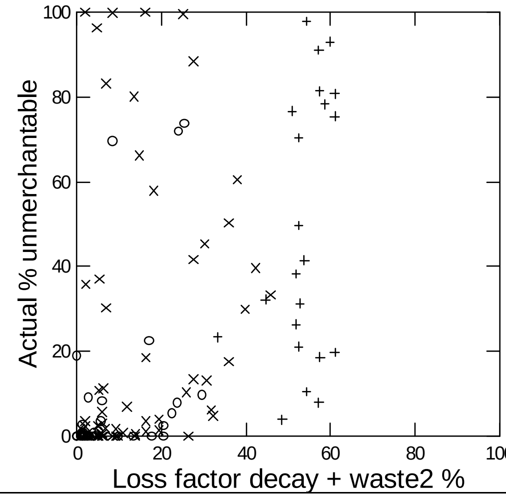

Figure 30: Relationship between actual unmerchantable volume % and loss factor estimates of decay and waste 2%. NOTE: o's represent risk group 1 trees; x are risk group 2; + are risk group 3.

With the exception of the live mature balsam stratum, the sampling errors for the NVAF ratios in Table 8 were well over 10%. This high degree of variability in the “sawable” NVAF’s is illustrated in Figures 31 and 32, which show the ratios of actual “sawable” volume over estimated CU net DW2 volume for individual sample trees within each stratum.

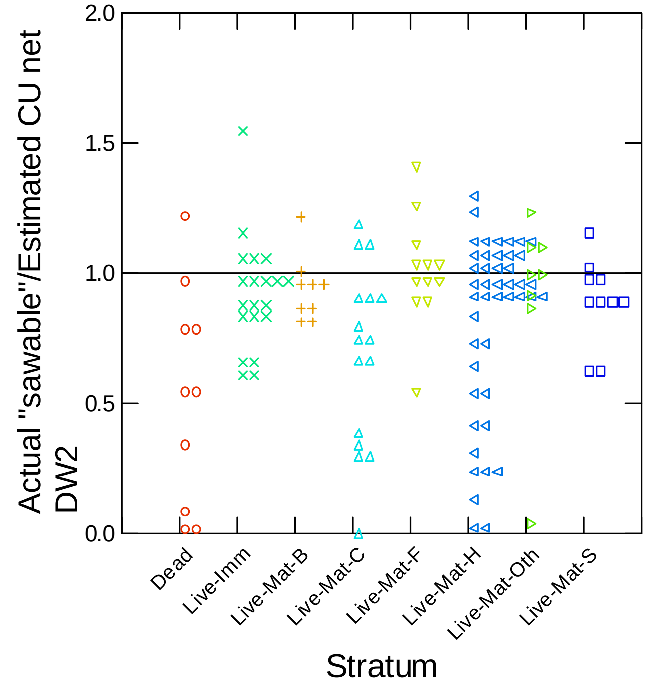

Figure 31: Ratios of actual “sawable” volume over estimated CU net DW2 volume (BEC-based taper and net factoring), by stratum.

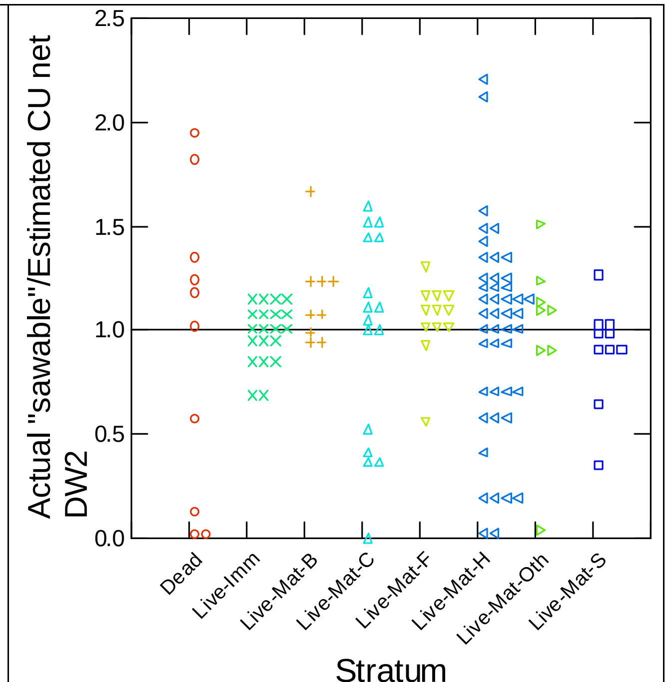

Figure 32: Ratios of actual “sawable” volume over estimated CU net DW2 volume (Revenue Branch taper and FIZ loss factors), by stratum.

When compared with the NVAFs to correct for bias in taper and decay & waste (i.e. Table 3), Table 8 indicates that correcting for sawability further reduces volume under both volume estimation systems, as expected. The values in Table 9 can be interpreted as an incremental correction in volume related to sawability (merchantability) compared with the standard NVAF values that corrects for bias in taper and decay & waste estimation (i.e. Table 3). Table 9 shows that all of the volume corrections are negative i.e. to correct for sawability, the estimated volumes must be further reduced.

Table 9: Incremental volume change associated with going from net decay and waste to net sawable[31].

NVAF stratum	***n* (number of sample trees)**	***% change in volume due to going from net decay & waste to net sawable***	
		BEC-based taper and net factoring	*Revenue Branch taper and FIZ loss factors*
Balsam	9	-3%	-4%
Cedar	16	-22%	-29%
Douglas-fir	12	-1%	-1%
Hemlock	45	-15%	-21%
Spruce	10	-5%	-10%
Other Species	8	-1%	-1%
Immature	20	-3%	-3%
Dead	10	-30%	-41%

From Table 9, the greatest correction for sawability among live trees (after accounting for bias in taper and decay estimation) occurred for cedar and hemlock. However, within these two species, there was considerable variability in the difference between actual CU sawable volume and actual CU net DW2 volume, on a tree-by-tree basis. The reduction for sawability or merchantability among the dead trees was particularly high, accounting for an incremental 30% and 41% reduction in volume based on net factoring and loss factors respectively.

3.6 Merchantable volume and log grade estimation

This section explores using the merchantable volume data collected from destructive sampling to provide better information for determining log grade distribution. Log grade distribution, in turn, can then be used to infer merchantability or sawability with more confidence. Note that the results presented herein are preliminary, are based on a small sample size and do not reflect NVAF sampling weights and hence must be interpreted with caution[32].

Under current standards, VRI cruiser-called grades are assigned on a log basis. This information was collected for the NVAF trees in TFL 23. The VRI log grades, which represent a modified version of coastal log grades, were subsequently grouped into two categories for this analysis, pulplog and sawlog[33]. Note that in the VRI, there is no preferred log length as there would be in scaling hence the

[31] These values are computed as the Table 8 NVAF value minus the Table 3 NVAF value.

[32] As a consequence, results in this section are restricted to graphical presentation. Tables showing ratios, volumes and percentages are not provided.

[33] The re-grade for the TFL 23 data was completed by Will Smith, FAIB. Log grades C, H, I, J & U were grouped into sawlogs and log grades N, P, Q, R, U & Y were grouped into pulplogs.

VRI log grades are more reflective of potential grade rather than actual grade, and typically underestimate mill recovery[34].

When the log grades were generalized into pulplog and sawlog for this analysis, one of the major criteria[35] for this categorization was the percentage of merchantable or sawable volume in the log. Hence the destructively sampled data on merchantable volume may provide the opportunity to strengthen the inferences for merchantable volume made indirectly via log grade. Through the VRI destructive sampling, there may be future potential for log grade distributions to be refined or potentially adjusted using the supplementary information provided by the actual measurement of unmerchantable volume collected in the NVAF destructive sampling.

VRI log grades are based on external features of log that are observable by the cruiser. Other than net factoring assumptions with regard to waste, there is no measure of unmerchantable wood volume. As a result, the log grades estimated by the cruisers may not be accurate even when grouped into the relatively general categories of pulplog and sawlog. On the other hand, there are external factors related to grade that are not explicitly captured in the call grading data collection (e.g. sweep, knots) but that may affect the grade called by the cruisers. So although the destructive sampling may provide better information on unmerchantable volume, other factors such as sweep and knots are also important determinants of grade.

To illustrate this with the destructively sampled data from TFL 23, although most call-graded sawlogs had low percentages of actual unmerchantable volume, there were still a number of logs that were graded by the cruiser as sawlog but that had greater than 80% actual unmerchantable volume. Similarly, nearly 40% of the cruiser-called pulplogs had less than 10% actual unmerchantable volume. Note however, that a log could be called a pulp grade for reasons other than unmerchantable volume (e.g. sweep, knots, etc.). These relationships are shown in Figures 33 and 34.

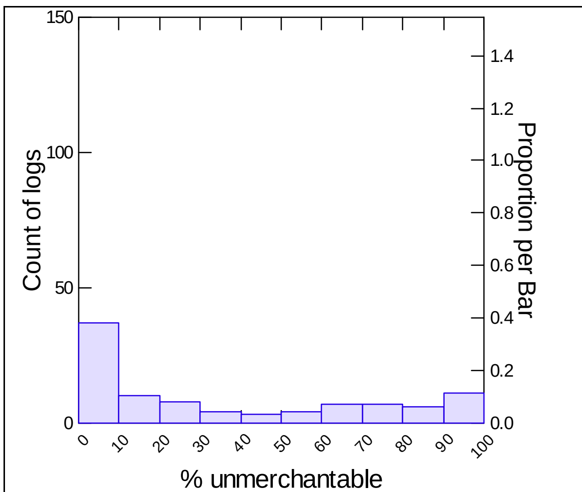

Fig 33: Distribution of logs by % actual unmerchantable volume for cruiser-called pulplogs.

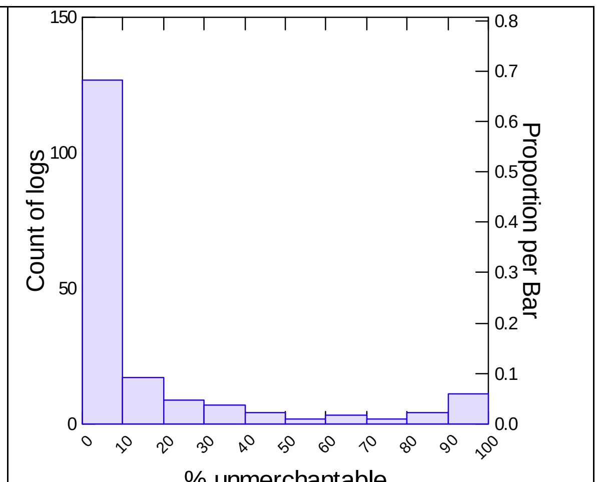

Fig 34: Distribution of logs by % actual unmerchantable volume for cruiser-called sawlogs.

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[34] Will Smith, pers. comm.

[35] Other criteria for assigning log grade include sweep, knots, etc. These could not be assessed here since they are captured only by virtue of the grade assigned by the cruiser and are not explicitly recorded in the VRI destructive sampling data collection process.

For this analysis, logs were "re-graded" using the additional information on actual unmerchantable volume provided by the destructive sampling[36]. Figure 35 below shows the percentage of logs that changed grade (from pulp to saw or vice versa) in this process.

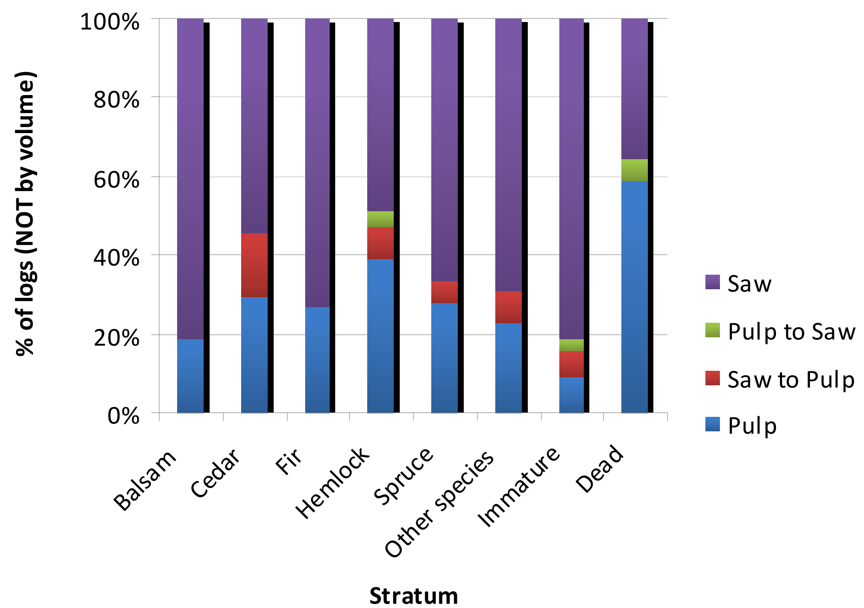


Fig 35: Percentage of individual logs in each grade category, by stratum for the NVAF trees in TFL 23. The bars also indicate logs that changed from pulp to saw and vice-versa when the actual unmerchantable volume % was factored into the grading decision (i.e. in the re-grade process). The data in this graph do not reflect the NVAF sample weights.

With the additional information on actual unmerchantable volume, a significant number of logs shifted from sawlog to pulplog in the cedar stratum. Although the re-grade resulted in shifts in both directions (i.e. pulp to saw and saw to pulp) in the hemlock and immature strata, more logs were shifted into the sawlog category.

The change in grade distribution between sawlogs and pulplogs, on a volume basis, is shown in Figure 36.

[36] Note that the re-grade may be biased since external features of the log that would have been observed by the cruiser were not captured in data collection and hence could not be factored into the re-grade decision.

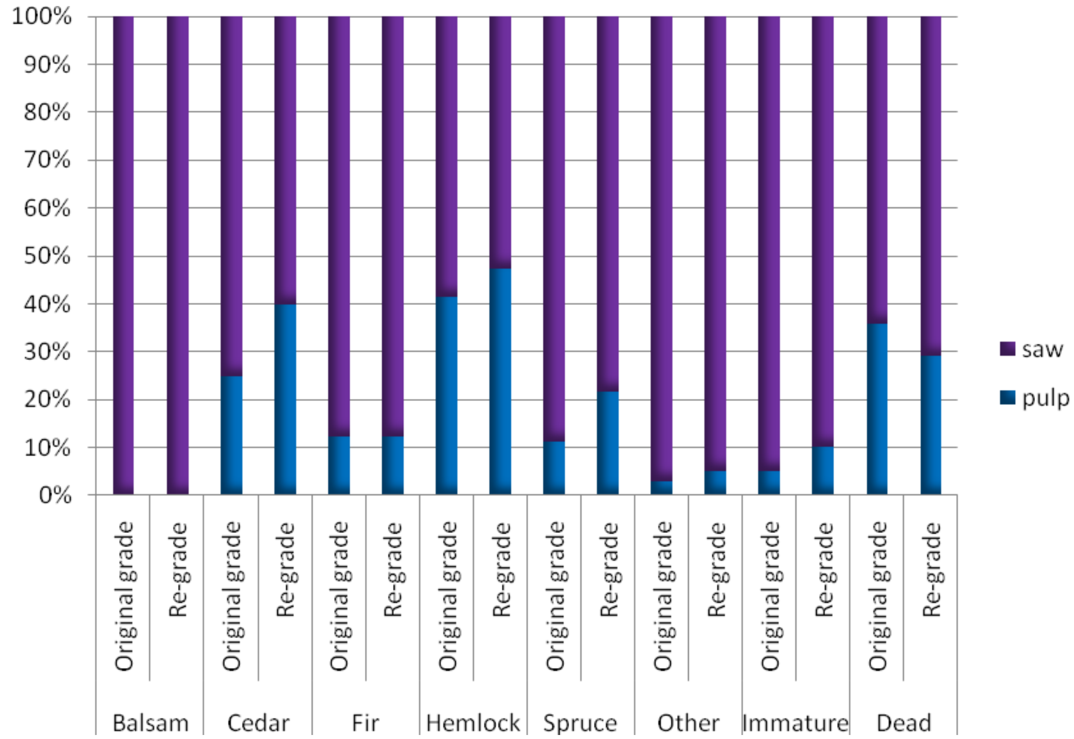


Figure 36: Comparison of the original cruiser-called grade distribution (i.e. sawlog vs. pulplog) with the re-grade distribution (i.e. based on the actual unmerchantable volume for each log). The grade distribution is shown on a volume percentage basis, where the volume is the estimated CU net DW2 (BEC-based taper and net factoring).

On a volume percentage basis, cedar once again showed the greatest shift from sawlog to pulplog. In this stratum, the re-grade in this analysis suggested that there was about a 15% volume shift from sawlogs to pulplogs compared with the original cruiser call grading. For hemlock, this preliminary analysis suggested about a 6% volume shift from sawlogs to pulplogs. Dead trees were the only stratum where volume shifted from the pulpwood category to the sawlog category.

4. CONCLUSIONS AND RECOMMENDATIONS

The NVAF values developed for the eight strata in Table 3 are recommended for use in adjustment of VRI Phase 2 ground sample volumes in TFL 23. The NVAFs in all strata suggested that the current VRI compiler, based on BEC taper and net factoring, overestimated CU net DW2 volume. The sampling errors associated with the NVAF values in the cedar and "other species" strata were relatively high. Additional sampling could improve the level of certainty associated with the NVAF in these strata. The sampling error in the hemlock stratum was also quite high despite the fact that this stratum included 45 sample trees. Given the concerns around volume overestimation in hemlock, further sampling may be warranted in an effort to improve the confidence in the hemlock NVAF value.

Although the BEC-based taper equations underestimated volume in hemlock, net factoring overestimated volume by an even greater percentage. The net result in the combination of these two errors, as reflected in the hemlock NVAF, was a modest 3% volume overestimation.

The difference between the decay and waste estimates for net factoring compared with loss factors was notable. Whereas net factoring *under*estimated decay and waste in hemlock in TFL 23, FIZ-based loss factors *over*estimated decay and waste in hemlock, by about 20% on average. The difference in the bias patterns for net factoring and loss factors is most notable in Risk Groups 1 and 3 where the loss factors were more likely to overestimate decay and waste for hemlock trees. This has significance for Revenue Branch appraisal cruising volume estimation.

Although NVAFs to correct for sawability were produced (see Table 8), there was high variability for these adjustment factors in most strata. This level of uncertainty may not be acceptable for all applications. However, additional sampling could improve the precision of such NVAFs.

As an alternative to developing sawable NVAFs, the unmerchantable volume data from destructive sampling could be used to increase the confidence in the estimated log grade distribution. This approach holds promise but requires further development. In particular, more work must be done to:

- consider implementing Interior Log Grades into the data collection system for VRIs in Interior management units to make the data collection more consistent with current log grade application;
- formalize a grade re-assessment based on actual unmerchantable volume;
- determine appropriate design or model-based weighting for logs within an NVAF sample tree.

5. APPENDIX A: PROJECT SPECIFICATIONS FOR UNMERCHANTABLE WOOD DATA COLLECTION IN NVAF SAMPLING PROJECTS

The following description is taken directly from the Merritt TSA NVAF Analysis report produced by Will Smith, Volume and Decay Officer, FAIB, MFR.

Overview

The Ministry of Forests and Range has been investigating the quantity of unmerchantable wood in order to better predict shelf life of MPB killed Lodgepole pine stands and to verify the estimates of sawlog volumes made from call grading of trees in VRI ground samples. The MOFR has tested the procedures in two NVAF sampling projects in 2007 and is recommending that the process become a standard procedure for NVAF sampling for the 2008 field season. The new process is based on MOFR scaling procedures for grade reduction. This document describes how the area of unmerchantable sound wood can be collected at each section of every NVAF sample tree.

Tree & Section Requirements

All sections for all trees will have an area of unmerchantable wood and defect and twist recorded.

Unmerchantable Wood Definition

MOFR scaling procedures capture the area of sound wood and associated defect that are considered to be uneconomic for milling; known as grade reduction. Grade reduction is composed of two parts: a 10 cm spacing between defects is too small to mill and a 2 cm wide trim allowance adjacent to defects which is lost to lumber recovery when squaring up the areas adjacent to the defect (see pages 6-17 to 6-23 of the April 1, 2006 Scaling Manual). Twist and knots which are normally considered in the scaling determination of merchantable wood will not be considered. Details are:

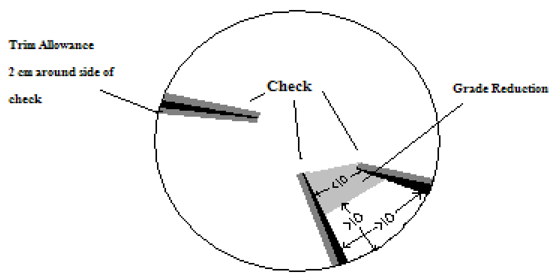
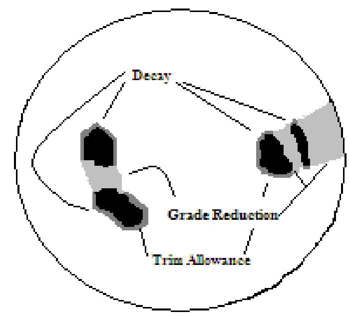
- Trim allowance:
    - 2 cm on each side of check (excluding inner point of check)
    - 2 cm around all sides of shake, bark seam, decay or hole (excluding sap rot and shallow scars)
- Unmerchantable sound wood size:
    - A 10 cm spacing between defects measured from defect to defect (not trim allowance to trim allowance).
    - Where all or portions of the soundwood collar are less than 15 cm thick for heart centered defects, rots or holes,
    - Otherwise where the soundwood collar (or portions) is less than 10 cm thick.
    - Sound hearts with a diameter less than 10 cm.

Attribute Definition: Weather Checks

A weather check is defined as a radial split from the outside of the bole of the tree that is at least 2 cm deep.

Measurement of Unmerchantable Wood

The area of the unmerchantable wood (trim and grade allowance) and the associated defects will be coalesced into one ellipse and captured as a stain using the DVHand software. Do not attempt to record each cause of unmerchantable wood separately, instead combine into one measure. Use a compound decay description to identify the principle cause of the degrade, use: CHK for checking, SHK for shake and DKY for decay. The length of the stain within a section would match that of the check as evidenced by the outside of the section or that of the existing decay – there will be no intermediate bucks required for unmerchanatable wood.

Figure 1. Unmerchantable wood due to checks	Figure 2. Unmerchantable wood due to decay
	

Measurement of Twist

The maximum twist found in each section will be measured as the displacement over a 30 cm length. The displacement will be measured to the nearest millimeter and will be recorded for all sections above 1.3 m with a twist displacement >= 2 cm. The portion of the tree between 0.3 and 1.3 m will be considered as one log. Capture section twist using DVHand by creating a stain with a compound decay description of 'FPD', a separate solid shape and record the displacement as width and breadth. For example: the width and breadth of a spiral for a section with a displacement of 2.3 cm would be recorded as 2.3 by 2.3; the top and bottom lengths would be recorded as 0.

6. APPENDIX B: NVAF VALUES FOR ALTERNATIVE VOLUME ESTIMATES

Although the current VRI standard for ground sample compilation is based on volume estimates using BEC-based taper and net factoring, alternative taper and loss systems have been used to estimate volume historically and for other purposes. Using the actual volumes from the destructively sampled trees, NVAF values were computed for four different compiled volume estimates:

A. NVAF with compiled volume estimates using BEC-based taper and Net Factoring (as would be used to adjust current VRI ground sample volumes);

B. NVAF with compiled volume estimates using FIZ-based taper and Net Factoring for decay (could have been used to adjust the volumes cited in the 2002 Sterling Wood VRI Adjustment Report);

C. NVAF with compiled volume estimates using FIZ-based taper and FIZ-based Loss Factors (can provide sensitivities around the 90's inventory audit samples);

D. NVAF with compiled volume estimates using Revenue Branch FIZ-based taper and FIZ-based Loss Factors (can provide sensitivities around the accuracy of appraisal cruise volumes).

These NVAFs are shown in Table B-1 below. The bias contribution of the taper system component and the decay estimation component of these volumes is detailed in Sections 3.2 and 3.3 of the main report.

Table B-1: NVAFs for alternative volume estimates (A-D see above), by stratum.

Stratum	*n (number of sample trees)*	***NVAF: Ratio of weighted actual CU net dw2 vol/ wt'd estimated CU net dw2 vol and 95% sampling error***							
		A: BEC taper; net factoring		*B: FIZ taper; net factoring*		*C: FIZ taper; FIZ loss factors*		*D: Rev. Br. FIZ taper; FIZ loss factors*	
		NVAF	SE%	NVAF	SE%	NVAF	SE%	NVAF	SE%
Balsam	9	0.914	2.7	0.860	4.5	1.117	4.6	1.117	4.6
Cedar	16	0.970	10.3	0.916	9.1	1.254	11.9	1.389	14.0
Douglas-fir	12	0.967	8.0	1.023	8.7	1.062	8.3	1.062	8.3
Hemlock	45	0.972	13.6	0.867	14.5	1.162	7.6	1.238	7.6
Spruce	10	0.969	4.9	0.938	6.6	0.978	5.0	0.978	5.0
Other Species	8	0.995	11.9	1.007	13.8	1.061	15.6	1.061	15.6
Immature (all species)	20	0.942	9.3	0.975	7.0	1.001	5.4	1.016	5.2
Dead (all species)	10	0.930	24.6	0.863	26.4	1.559	13.2	1.559	13.2

7. APPENDIX C: NVAF RELATIONSHIPS, BY STRATUM FOR ADJUSTMENT OF CU NET DW2 VOLUME (BEC TAPER, NET FACTORING)

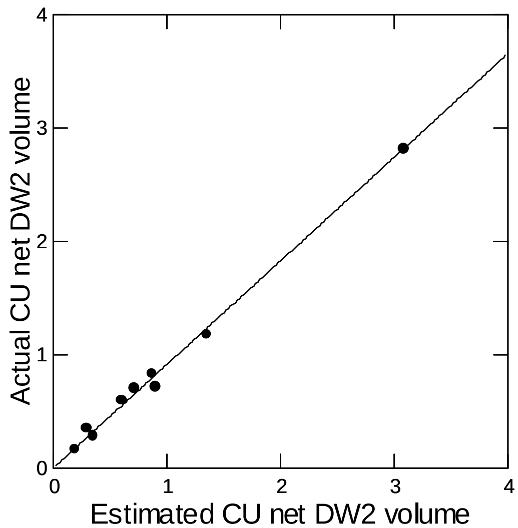


Fig. C-1: Balsam stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

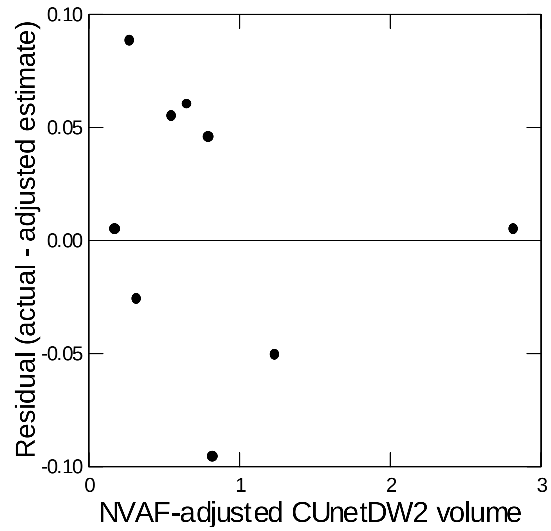


Fig. C-2: Balsam stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

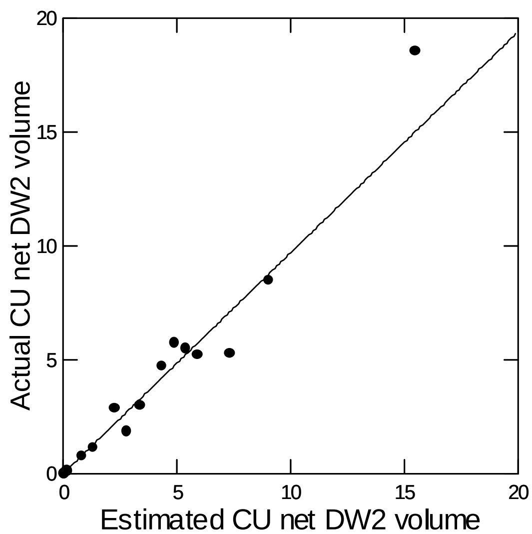


Fig. C-3: Cedar stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

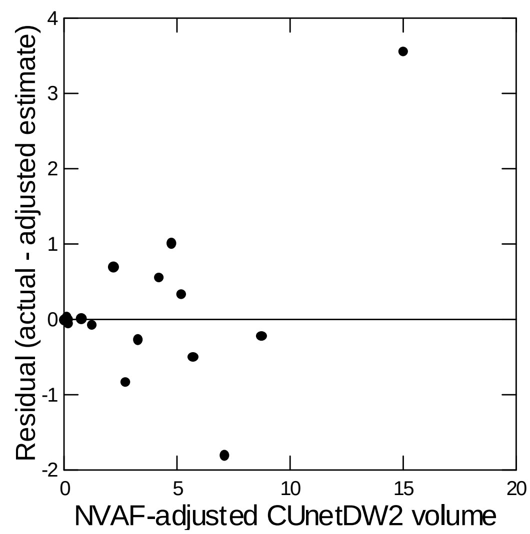


Fig. C-4: Cedar stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

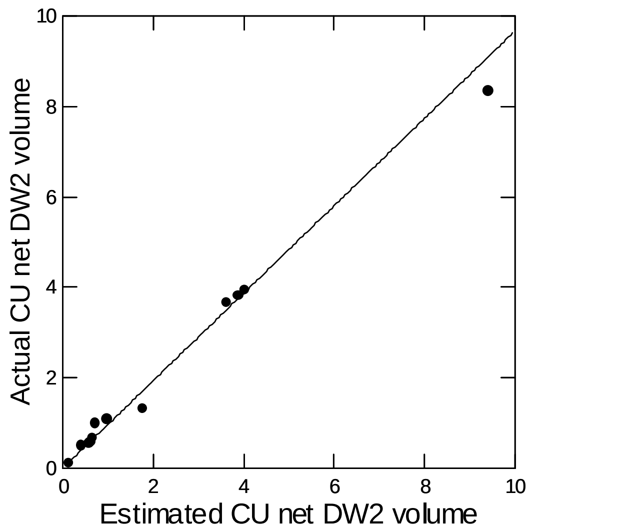


Fig. C-5: Douglas-fir stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

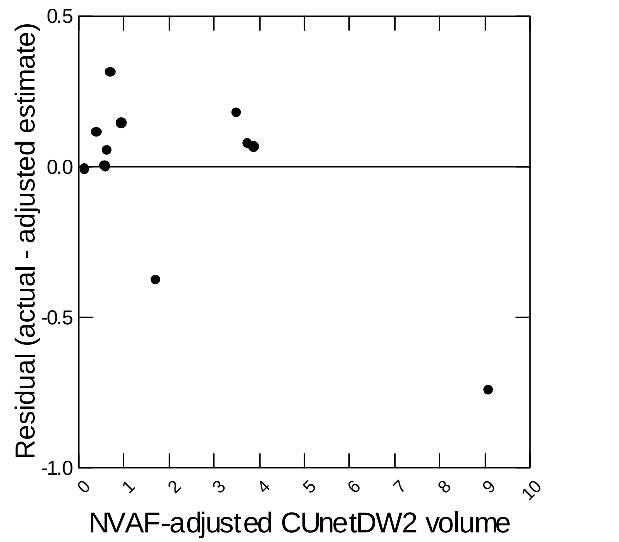


Fig. C-6: Douglas-fir stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

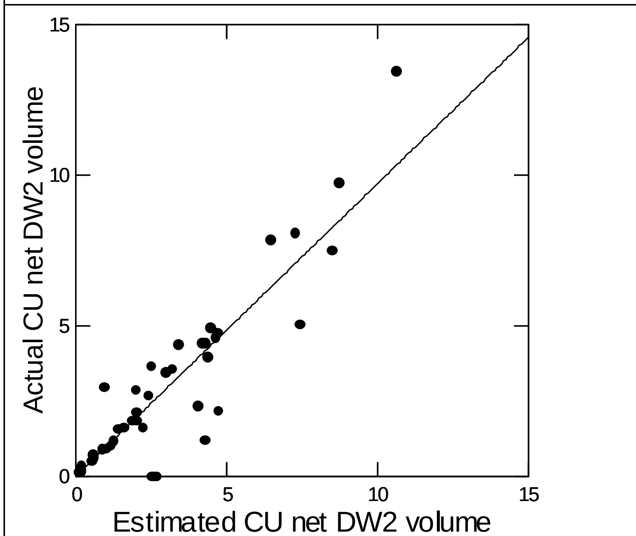


Fig. C-7: Hemlock stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

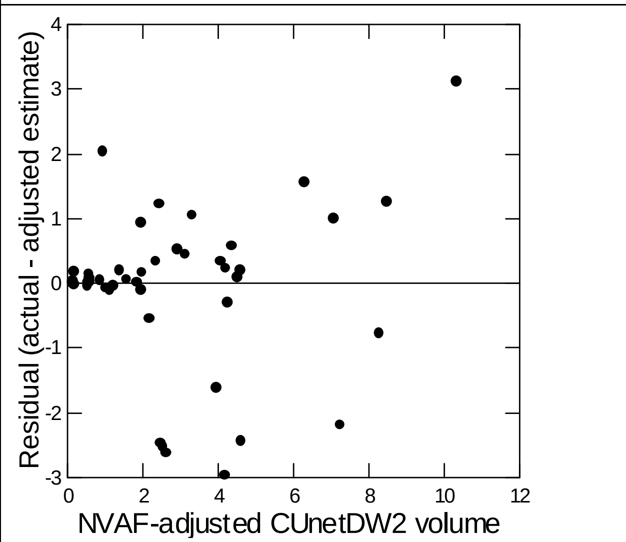


Fig. C-8: Hemlock stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

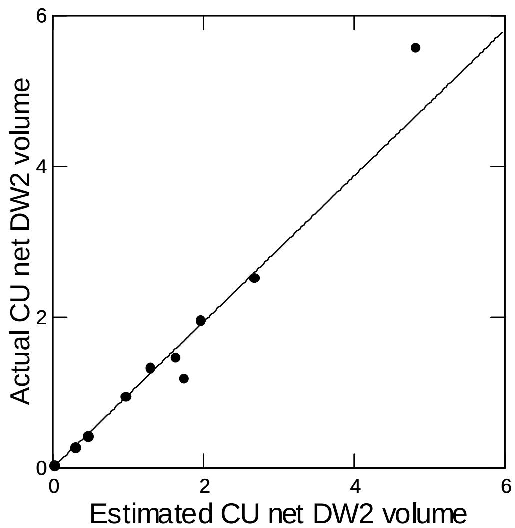


Fig. C-9: Spruce stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

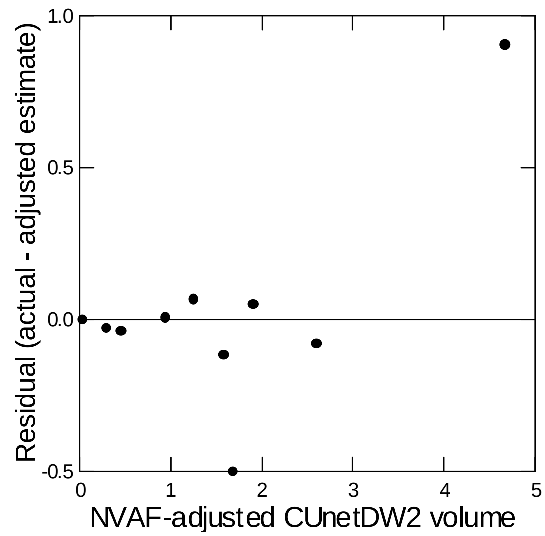


Fig. C-10: Spruce stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

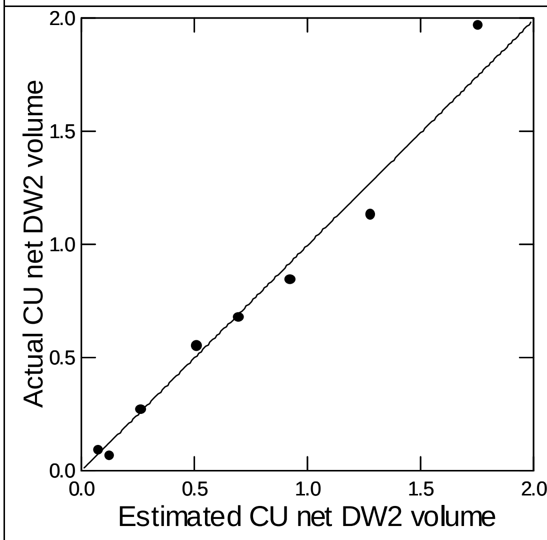


Fig. C-11: "Other species" stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

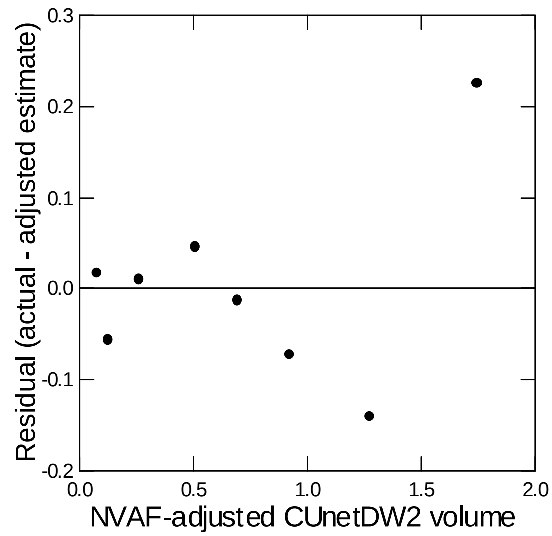


Fig. C-12: "Other species" stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

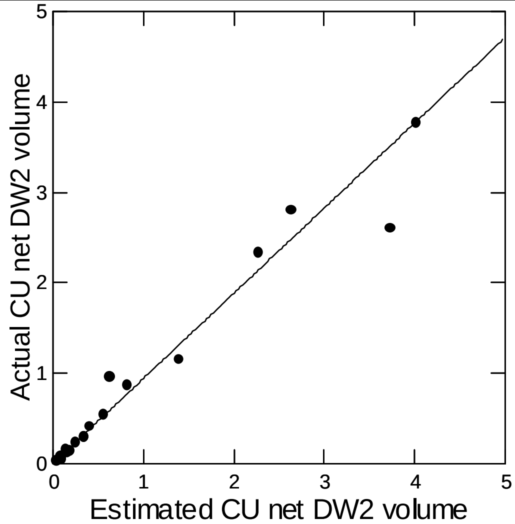


Fig. C-13: Immature (all species) stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

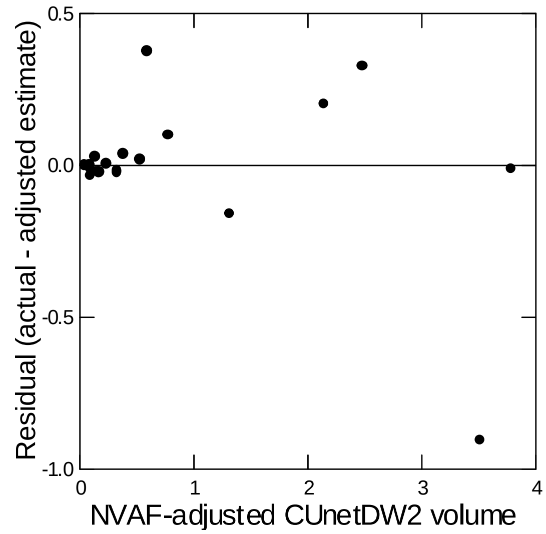


Fig. C-14: Immature (all species) stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

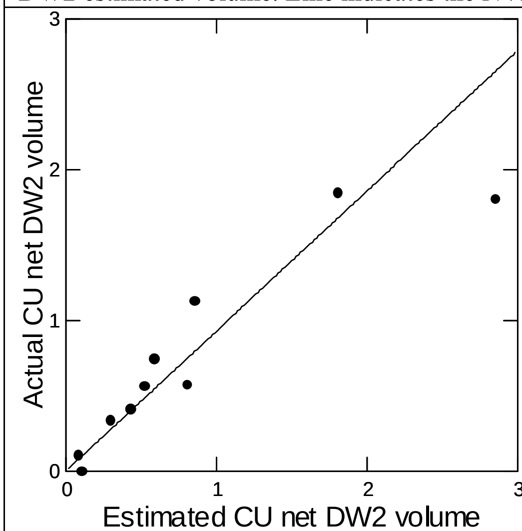


Fig. C-15: Dead (all species) stratum – actual CU net DW2 volume vs. BEC-taper net factored CU net DW2 estimated volume. Line indicates the NVAF ratio.

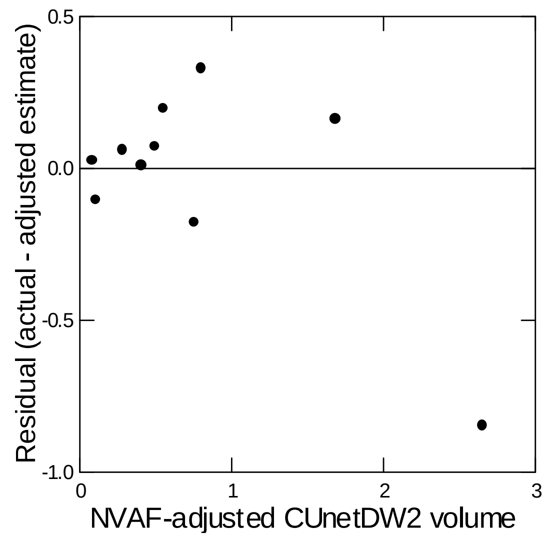


Fig. C-16: Dead (all species) stratum residuals after NVAF is applied. Residual (actual – NVAF*estimate) vs. NVAF*estimate.

8. APPENDIX D: CU VOLUME TAPER BIAS GRAPHS BY STRATUM

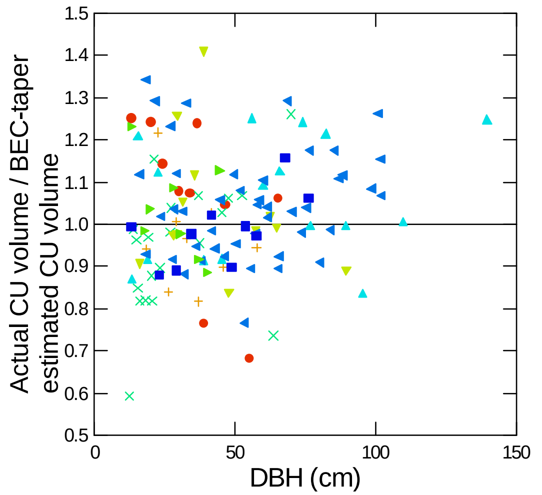


Fig. D-1: BEC-based taper equation bias for individual samples, as a function of dbh.

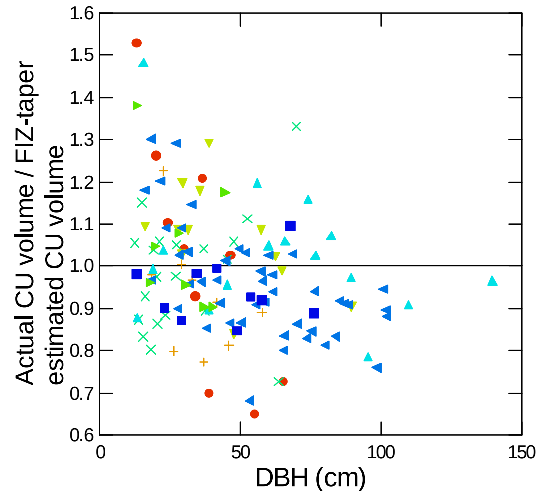


Fig. D-2: FIZ-based taper equation bias for individual samples, as a function of dbh.

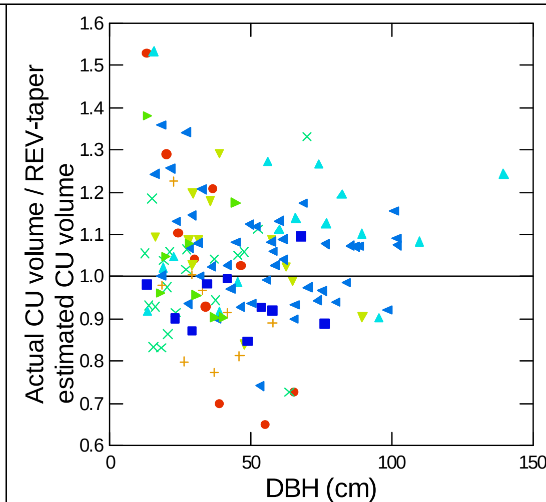
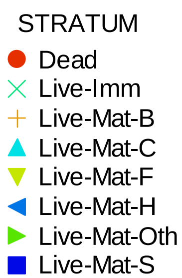


Fig. D-3: Revenue Branch FIZ-based taper equation bias for individual samples, as a function of dbh.



Live Mature Balsam Stratum:

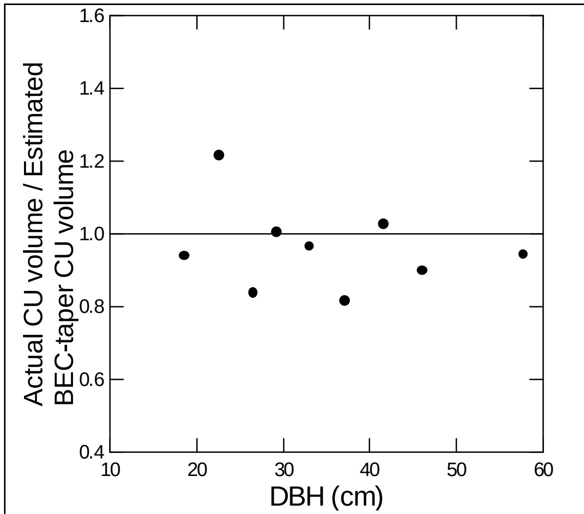


Fig. D-4: BEC-based taper equation bias vs dbh.

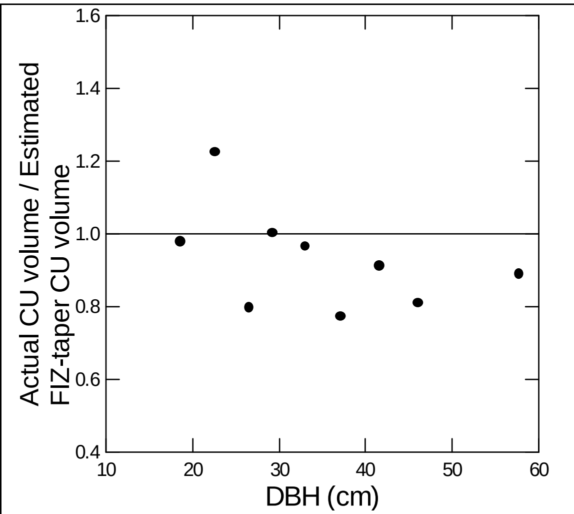


Fig D-5: FIZ-based taper equation bias vs dbh.

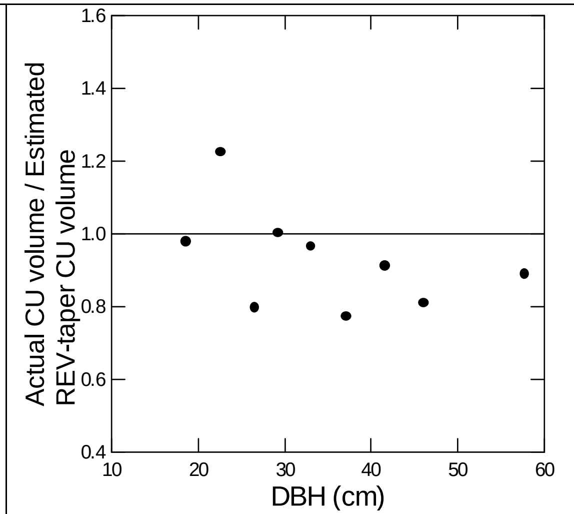


Fig D-6: Revenue Branch FIZ-based taper equation bias vs dbh.

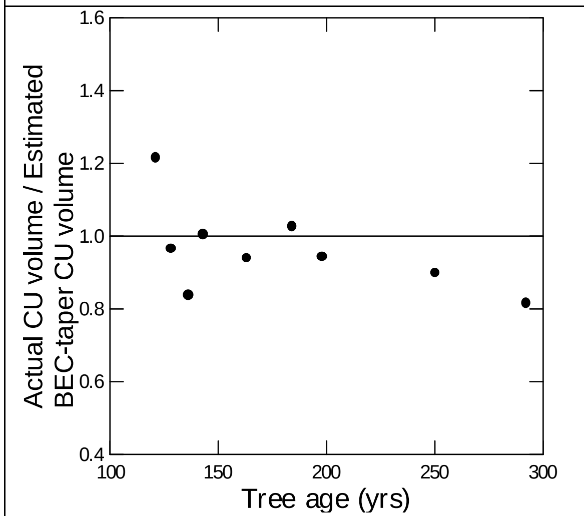


Fig D-7: BEC-based taper equation bias vs tree age.

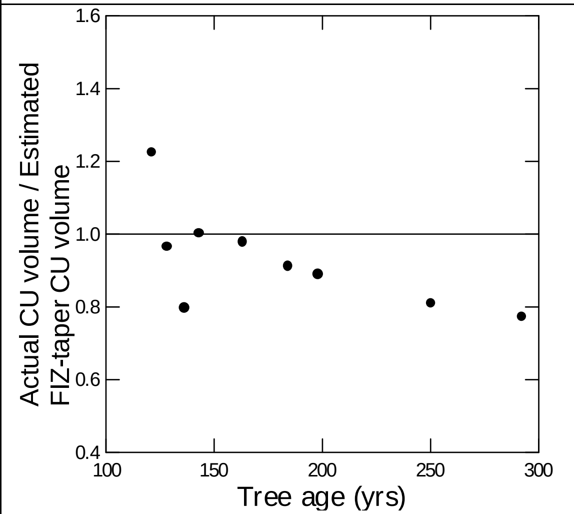


Fig D-8: FIZ-based taper equation bias vs tree age.

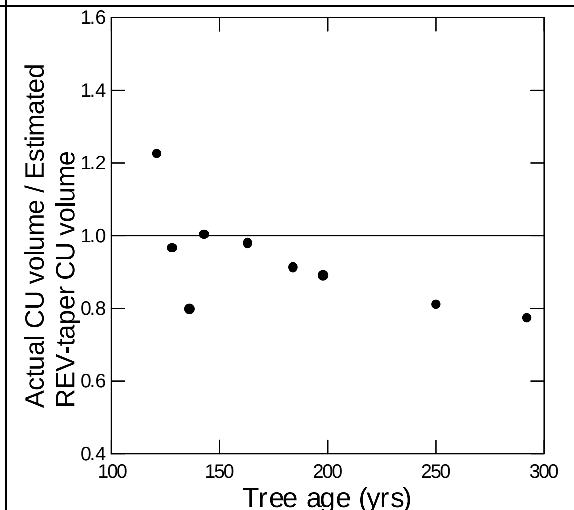


Fig D-9: Revenue Branch FIZ-based taper equation bias vs tree age.

Live Mature Balsam Stratum (cont'd):

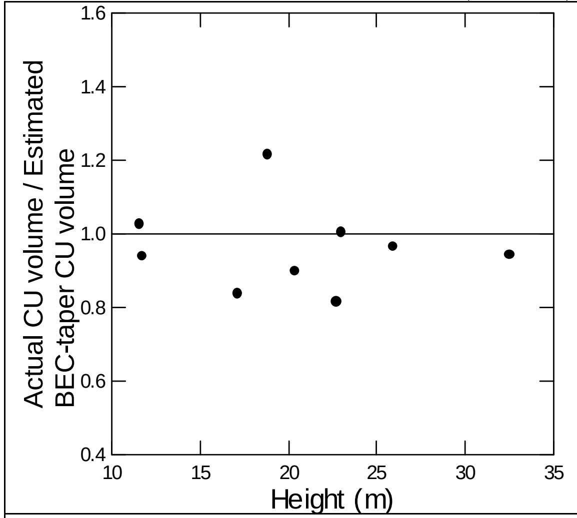


Fig D-10: BEC-based taper equation bias vs tree height.

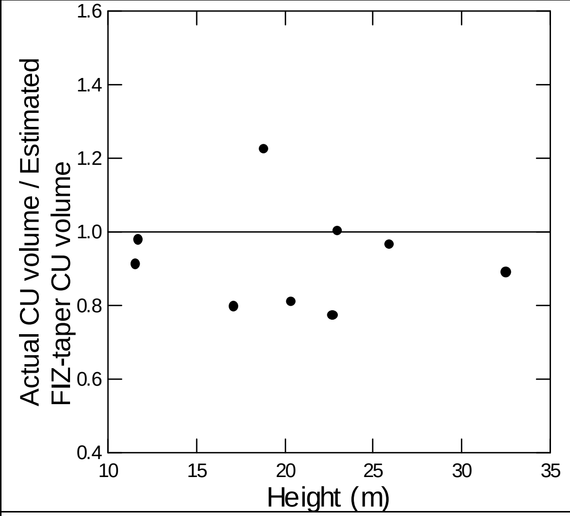


Fig D-11 FIZ-based taper equation bias vs tree height.

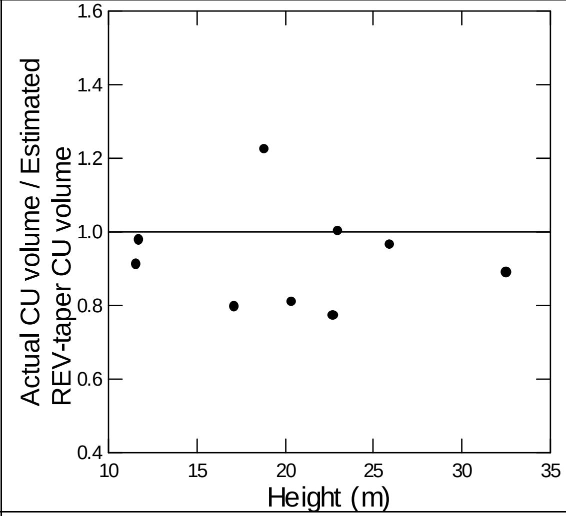


Fig D-12: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Mature Cedar Stratum:

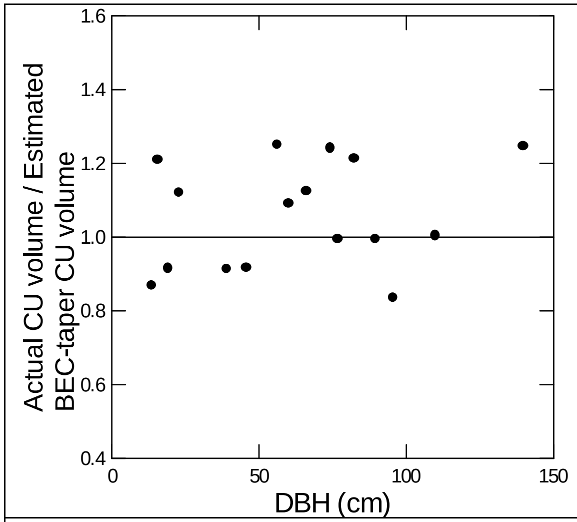


Fig. D-13: BEC-based taper equation bias vs dbh.

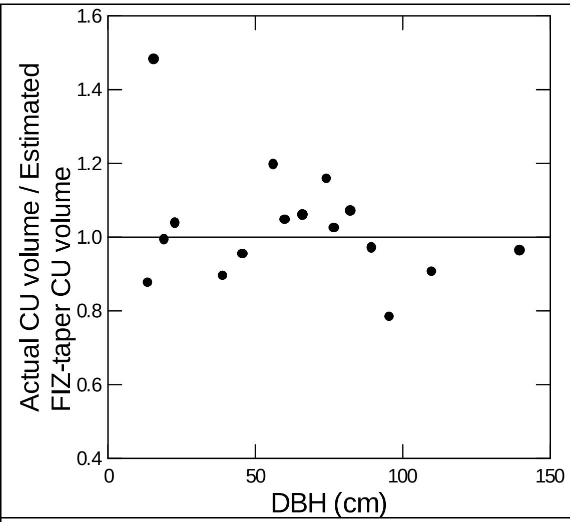


Fig D-14: FIZ-based taper equation bias vs dbh.

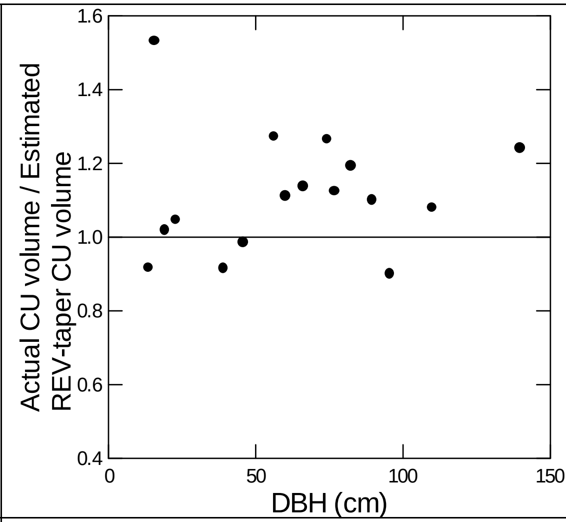


Fig D-15: Revenue Branch FIZ-based taper equation bias vs dbh.

Live Mature Cedar Stratum (cont'd):

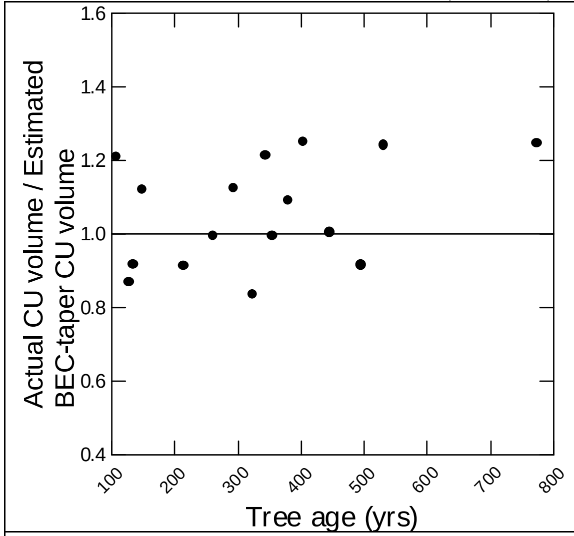


Fig D-16: BEC-based taper equation bias vs tree age.

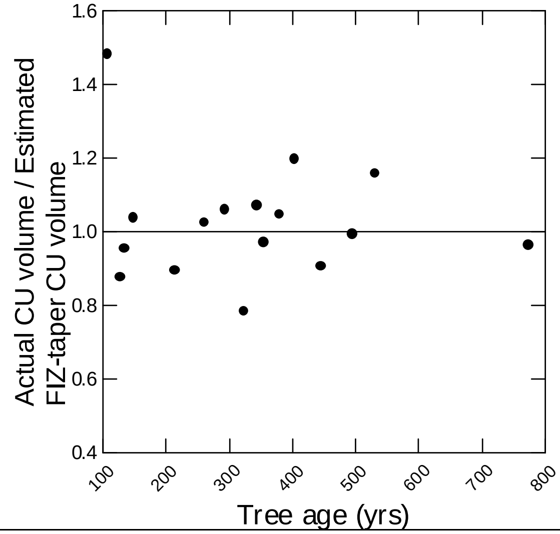


Fig D-17: FIZ-based taper equation bias vs tree age.

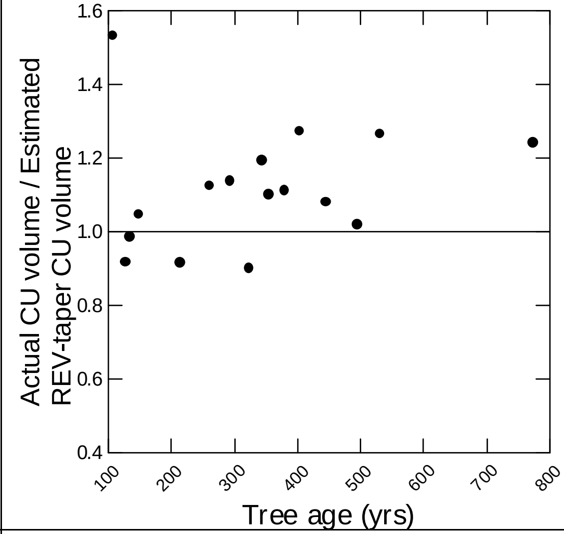


Fig D-18: Revenue Branch FIZ-based taper equation bias vs tree age.

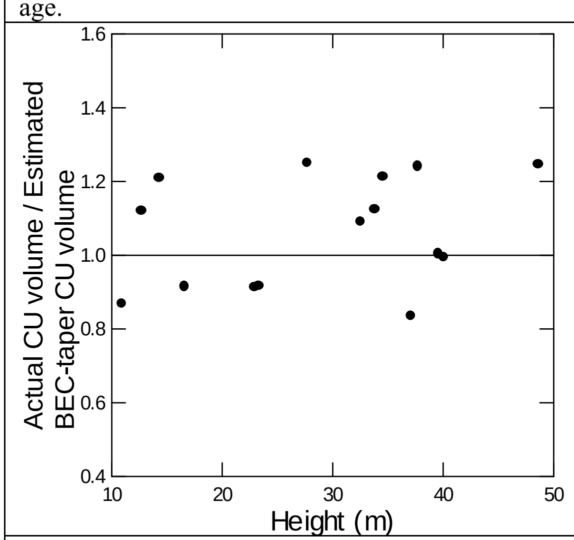


Figure D-19: BEC-based taper equation bias vs tree height.

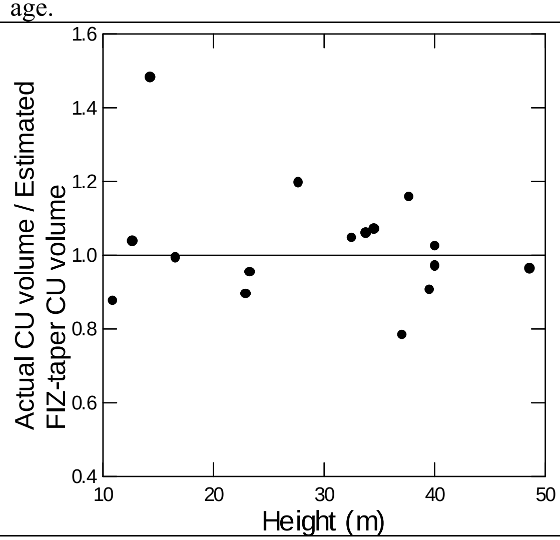


Figure D-20: FIZ-based taper equation bias vs tree height.

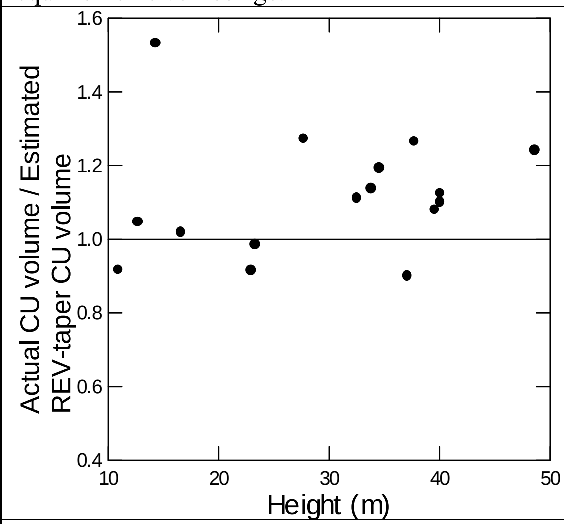


Figure D-21: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Mature Douglas-fir Stratum:

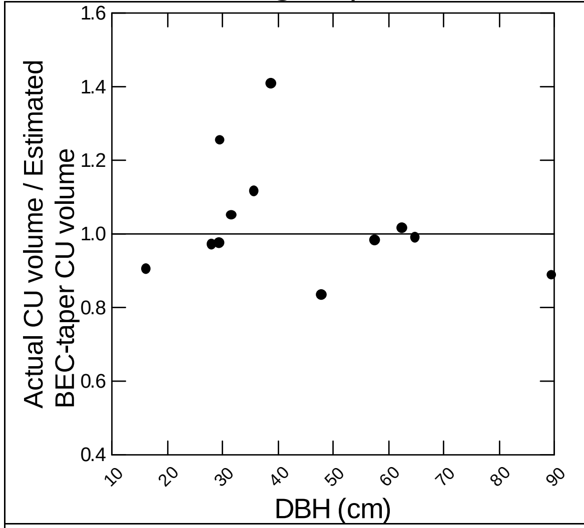


Fig. D-22: BEC-based taper equation bias vs dbh.

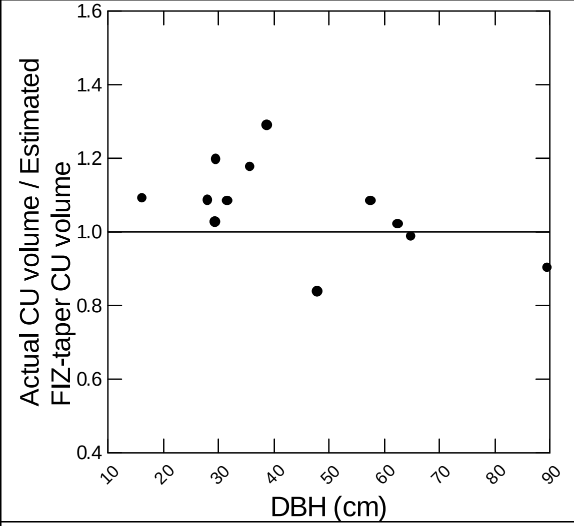


Figure D-23: FIZ-based taper equation bias vs dbh.

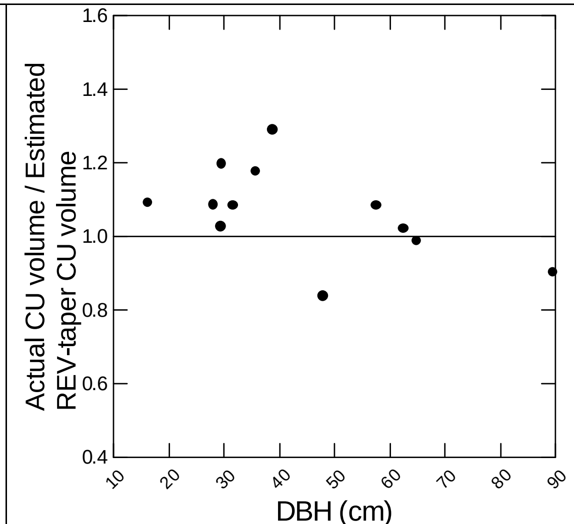


Figure D-24: Revenue Branch FIZ-based taper equation bias vs dbh.

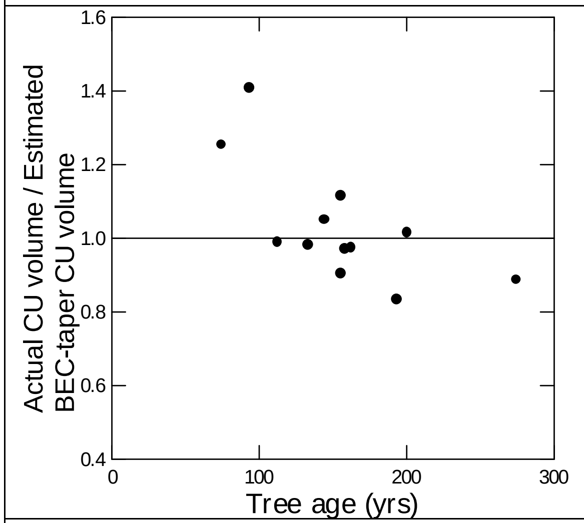


Figure D-25: BEC-based taper equation bias vs tree age.

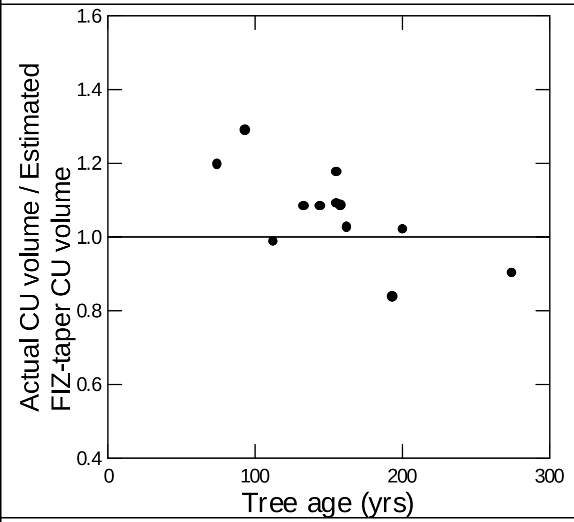


Figure D-26: FIZ-based taper equation bias vs tree age.

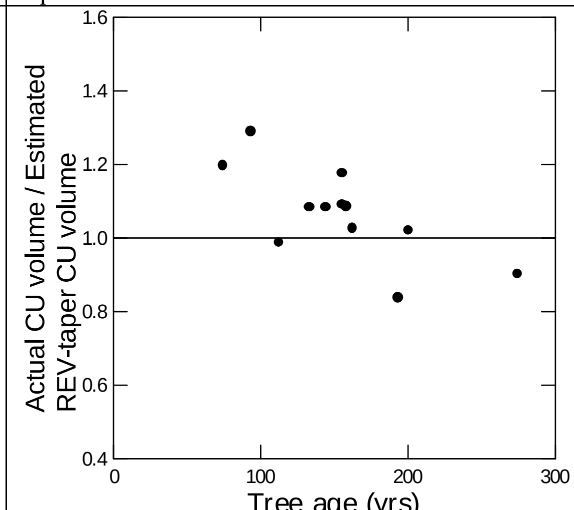


Figure D-27: Revenue Branch FIZ-based taper equation bias vs tree age.

Live Mature Douglas-fir Stratum (cont'd):

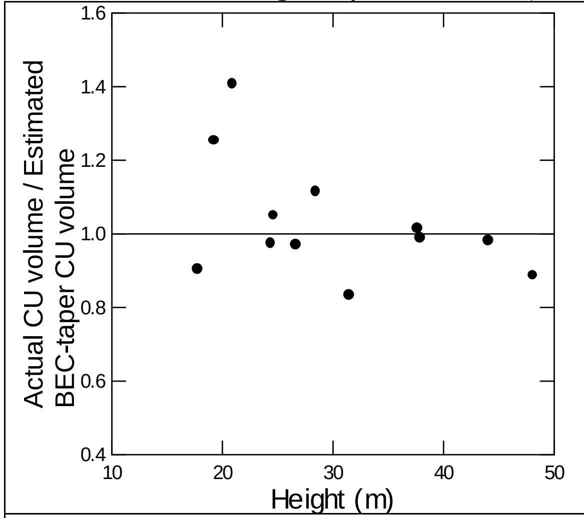


Figure D-28: BEC-based taper equation bias vs tree height.

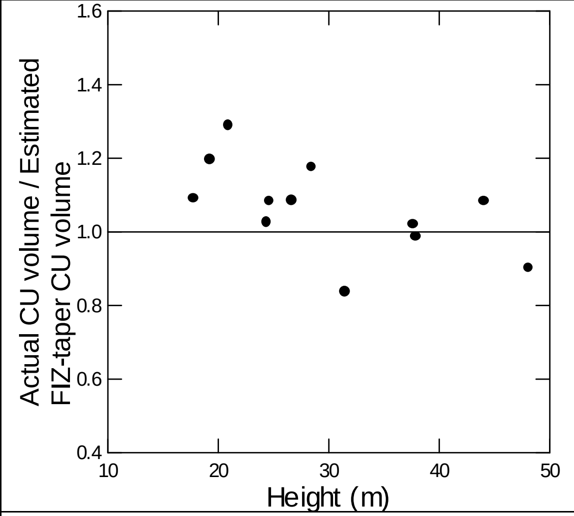


Figure D-29: FIZ-based taper equation bias vs tree height.

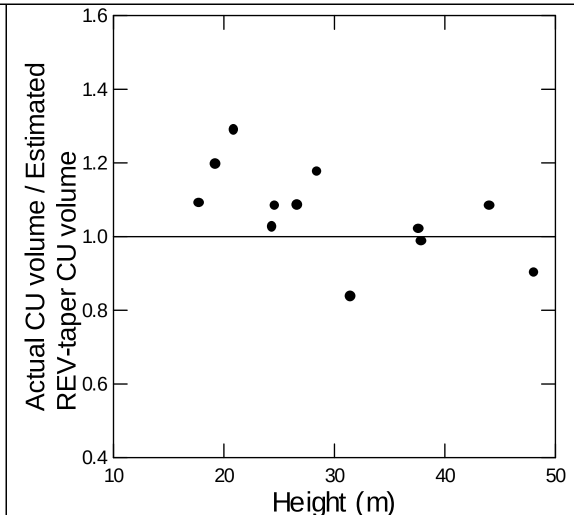


Figure D-30: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Mature Hemlock Stratum:

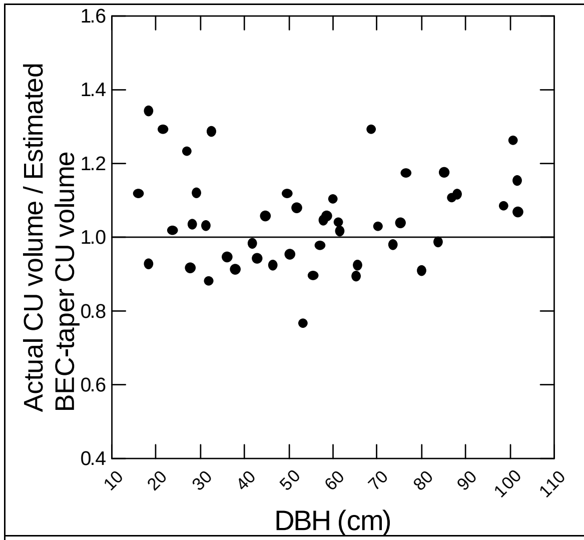


Fig. D-31: BEC-based taper equation bias vs dbh.

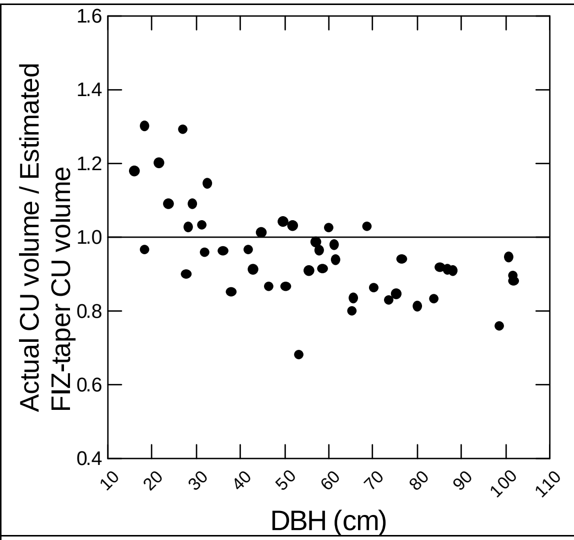


Figure D-32: FIZ-based taper equation bias vs dbh.

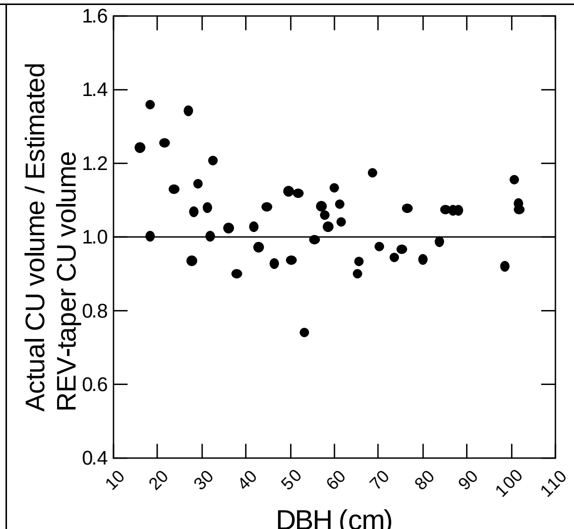


Figure D-33: Revenue Branch FIZ-based taper equation bias vs dbh.

Live Mature Hemlock Stratum (cont'd):

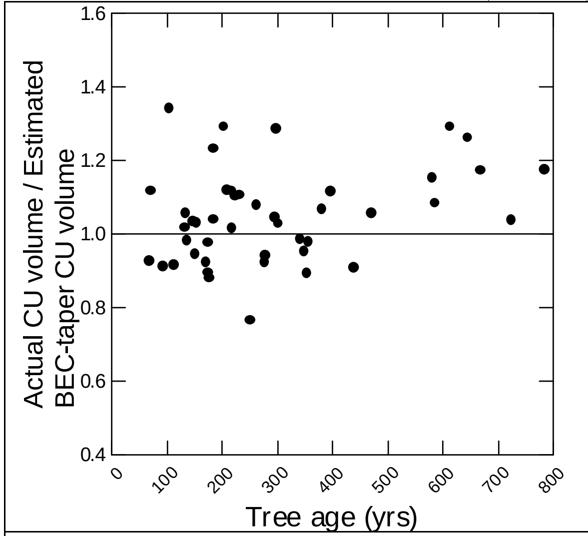


Figure D-34: BEC-based taper equation bias vs tree age.

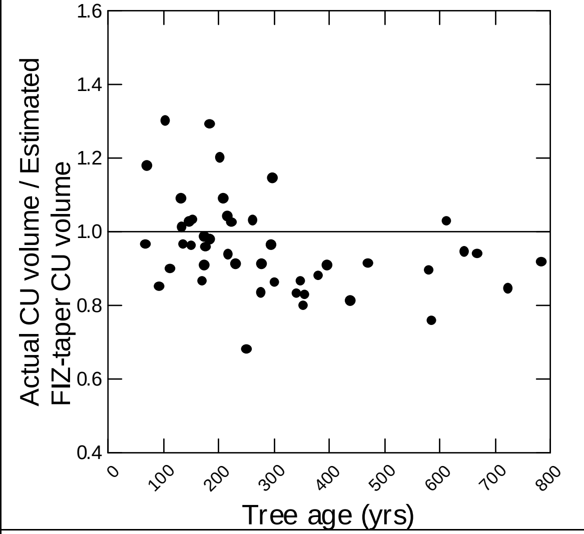


Figure D-35: FIZ-based taper equation bias vs tree age.

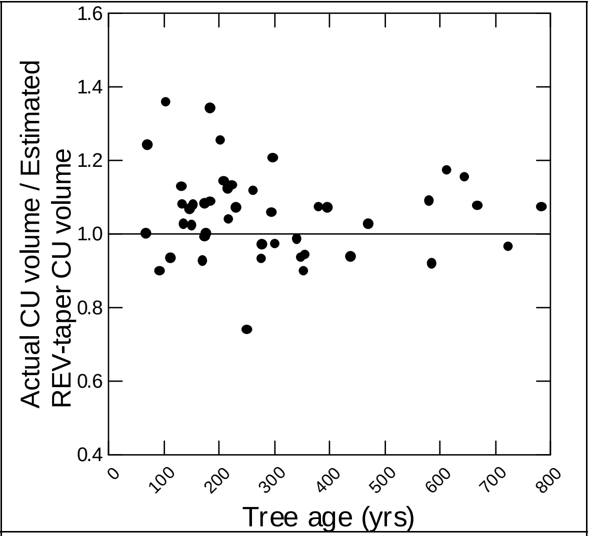


Figure D-36: Revenue Branch FIZ-based taper equation bias vs tree age.

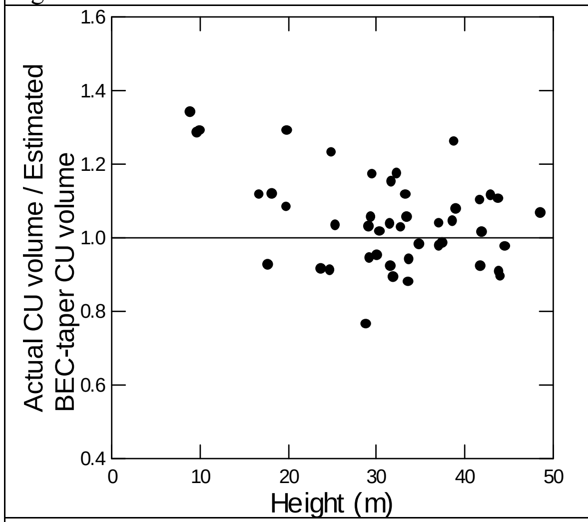


Figure D-37: BEC-based taper equation bias vs tree height.

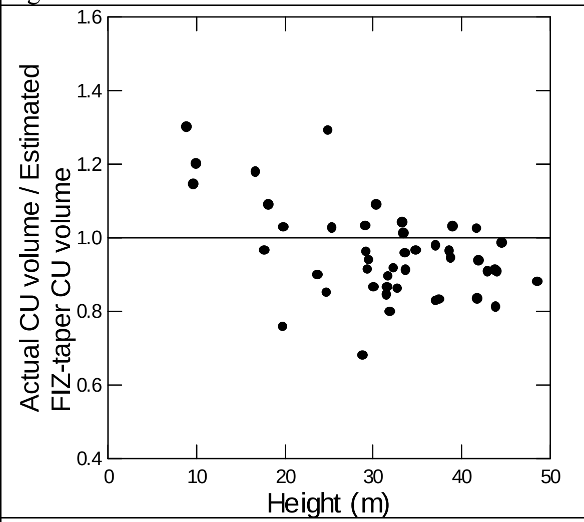


Figure D-38: FIZ-based taper equation bias vs tree height.

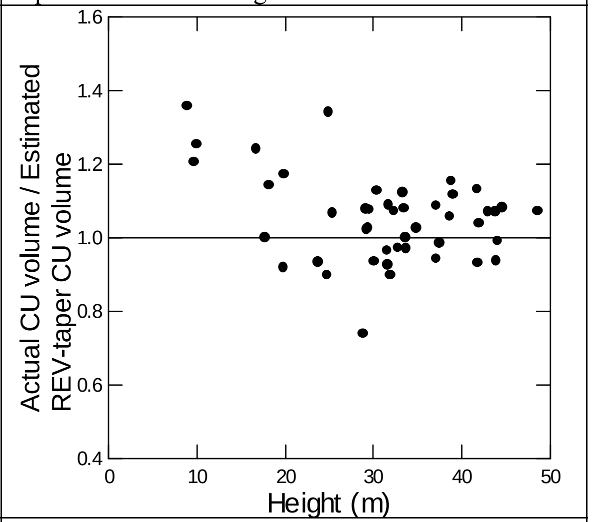


Figure D-39: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Mature Spruce Stratum:

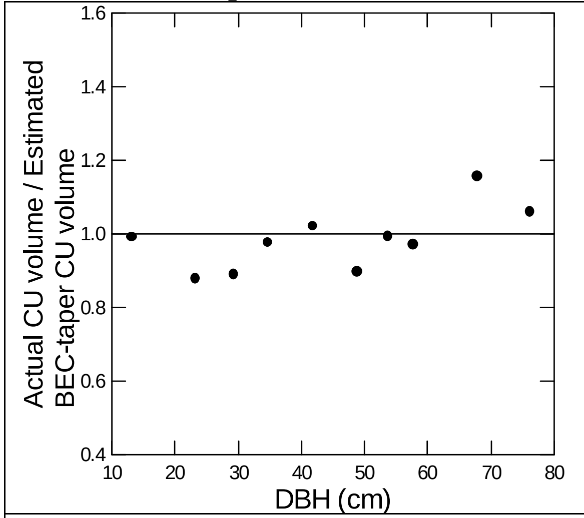


Fig. D-40: BEC-based taper equation bias vs dbh.

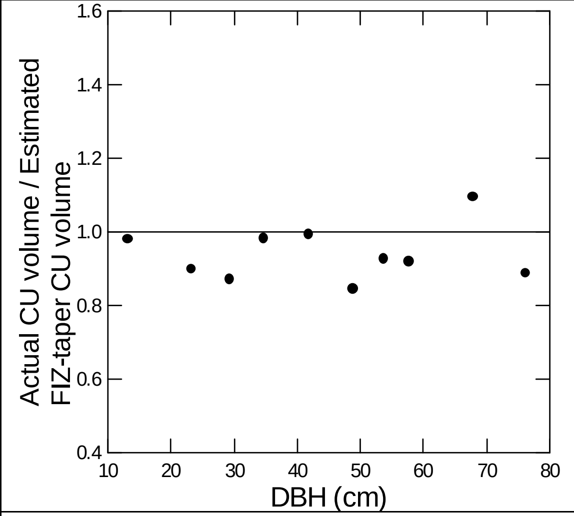


Figure D-41: FIZ-based taper equation bias vs dbh.

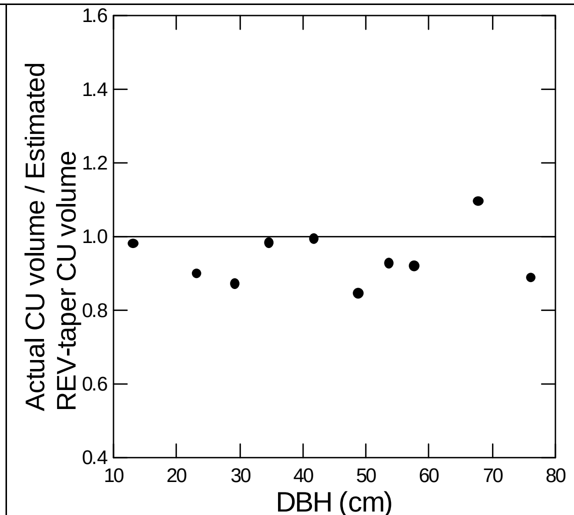


Figure D-42: Revenue Branch FIZ-based taper equation bias vs dbh.

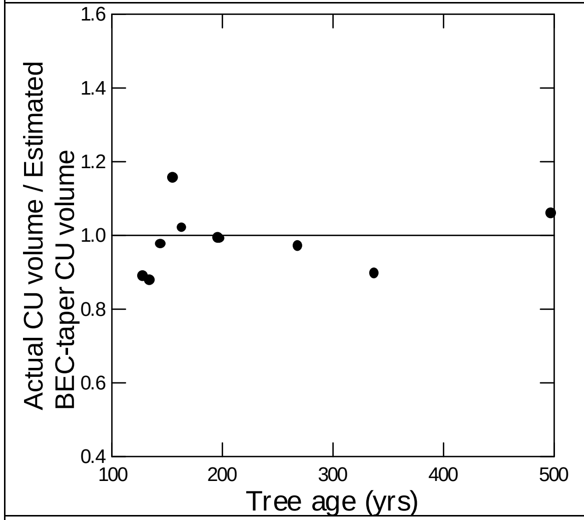


Figure D-43: BEC-based taper equation bias vs tree age.

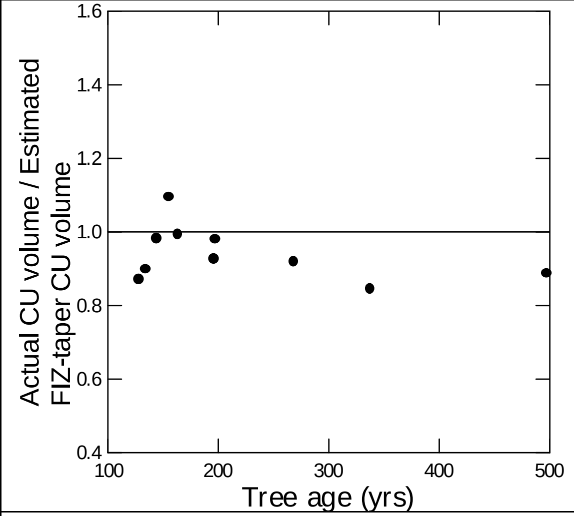


Figure D-44: FIZ-based taper equation bias vs tree age.

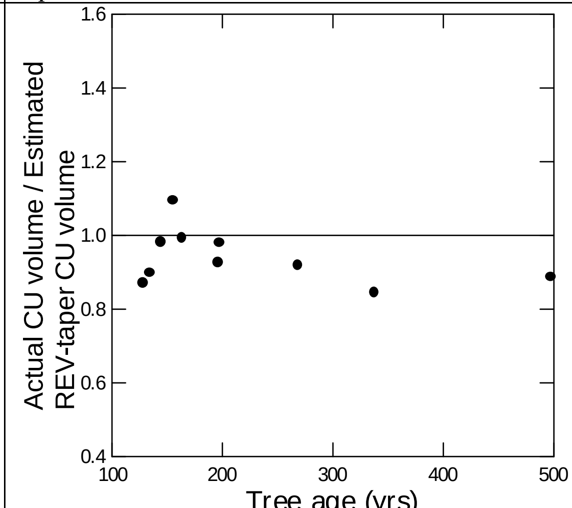


Figure D-45: Revenue Branch FIZ-based taper equation bias vs tree age.

Live Mature Spruce Stratum (cont'd):

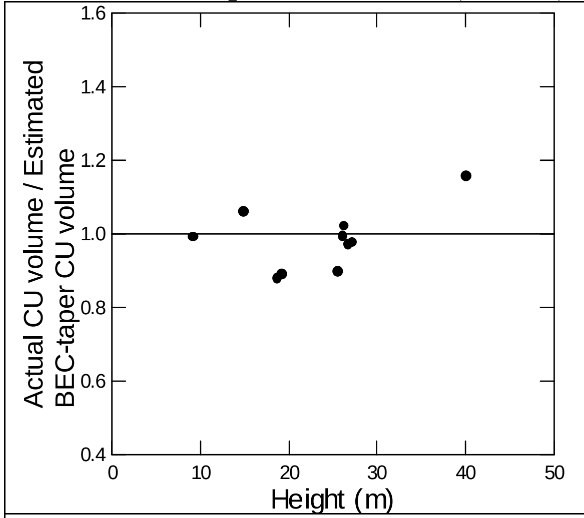


Figure D-46: BEC-based taper equation bias vs tree height.

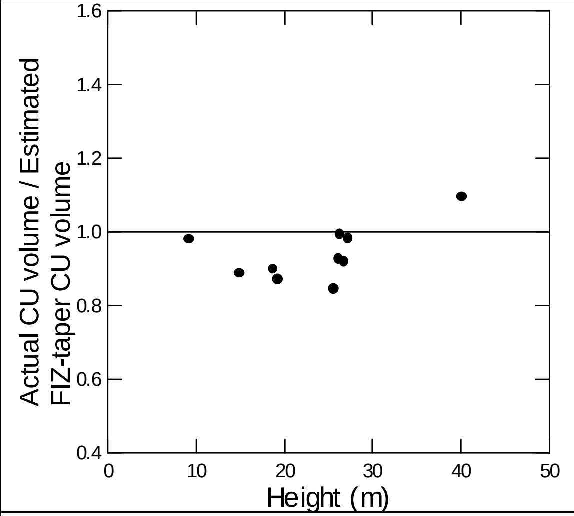


Figure D-47: FIZ-based taper equation bias vs tree height.

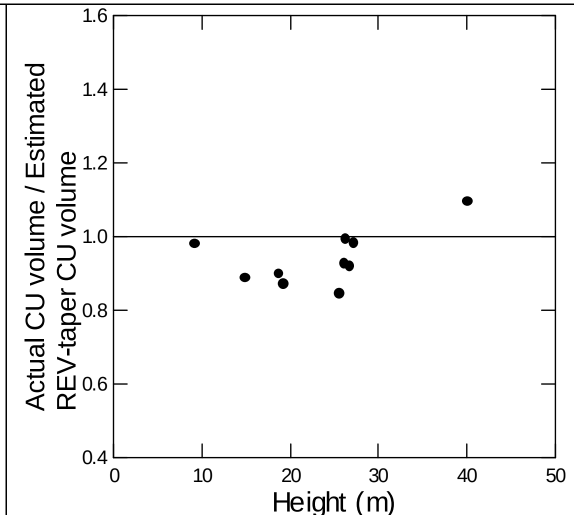


Figure D-48: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Mature "Other species" Stratum:

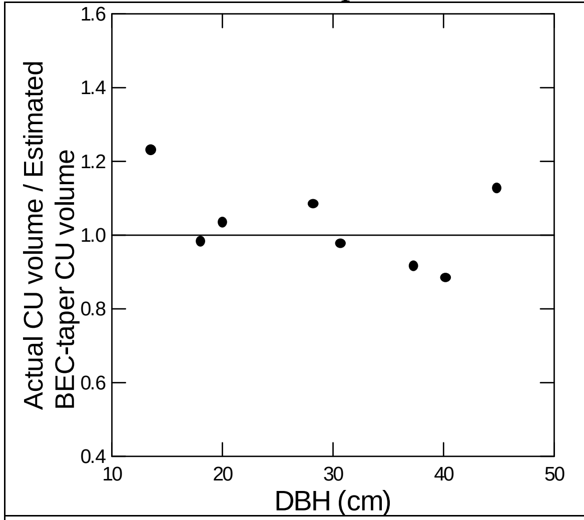


Fig. D-49: BEC-based taper equation bias vs dbh.

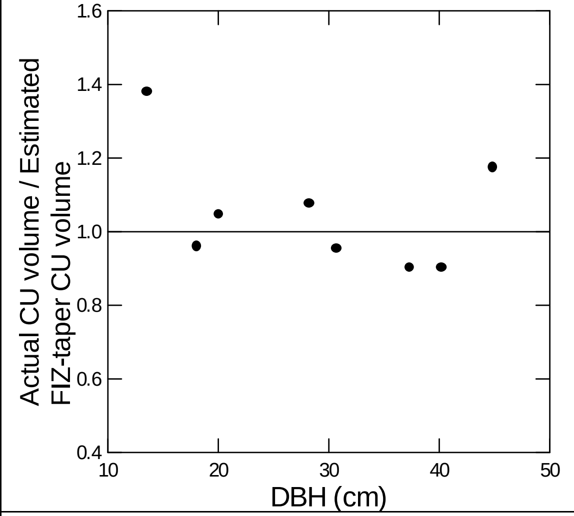


Figure D-50: FIZ-based taper equation bias vs dbh.

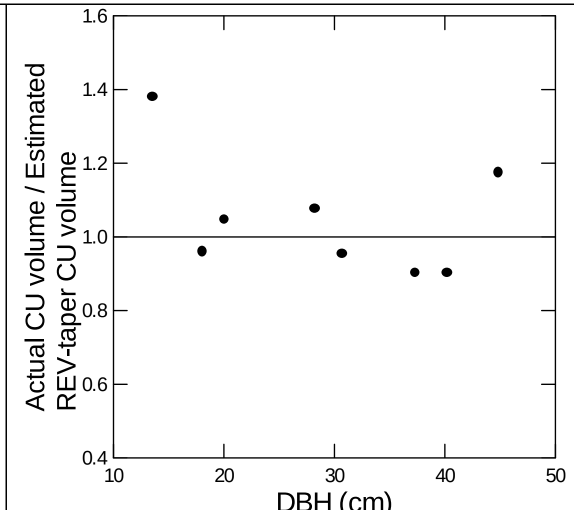


Figure D-51: Revenue Branch FIZ-based taper equation bias vs dbh.

Live Mature "Other species" Stratum (cont'd):

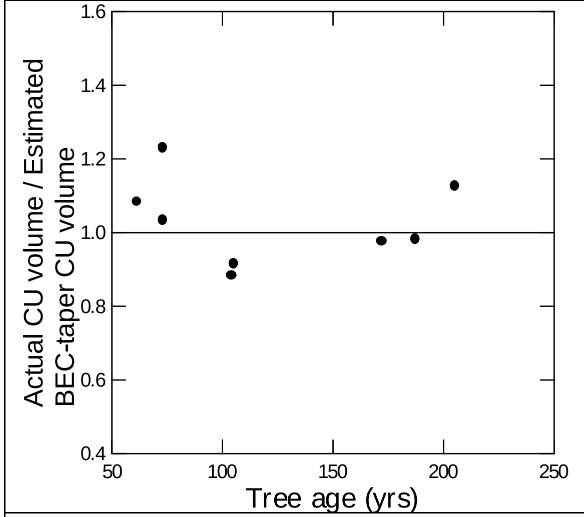


Figure D-52: BEC-based taper equation bias vs tree age.

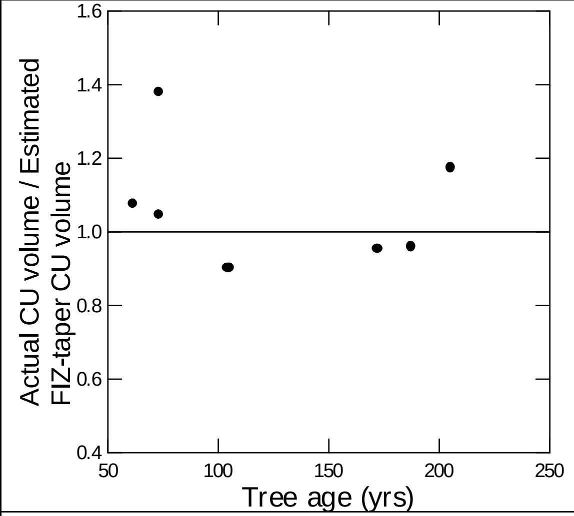


Figure D-53: FIZ-based taper equation bias vs tree age.

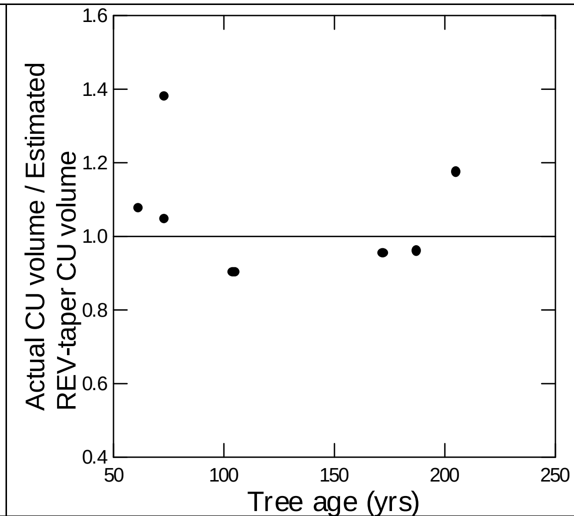


Figure D-54: Revenue Branch FIZ-based taper equation bias vs tree age.

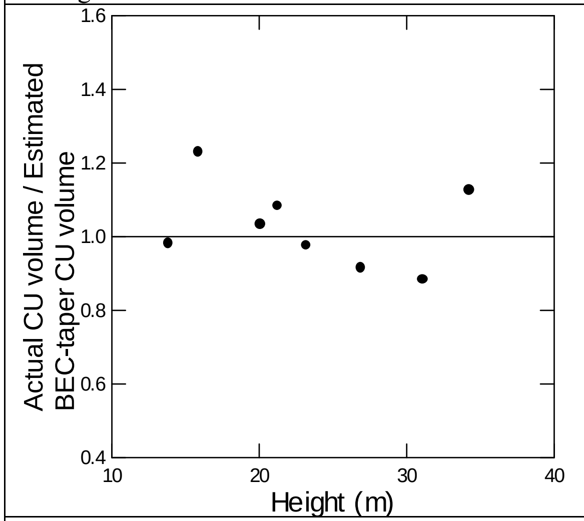


Figure D-55: BEC-based taper equation bias vs tree height.

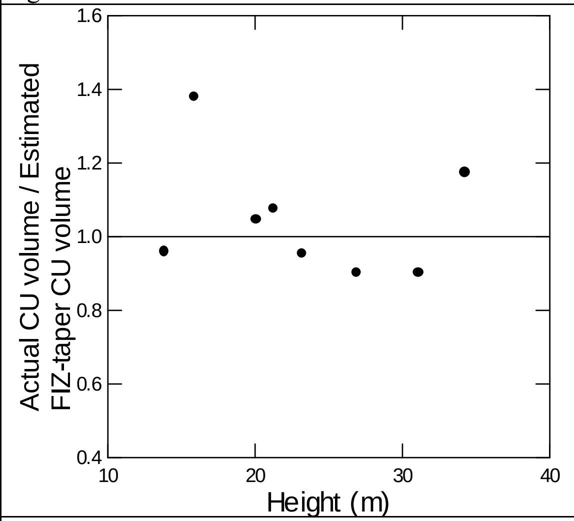


Figure D-56: FIZ-based taper equation bias vs tree height.

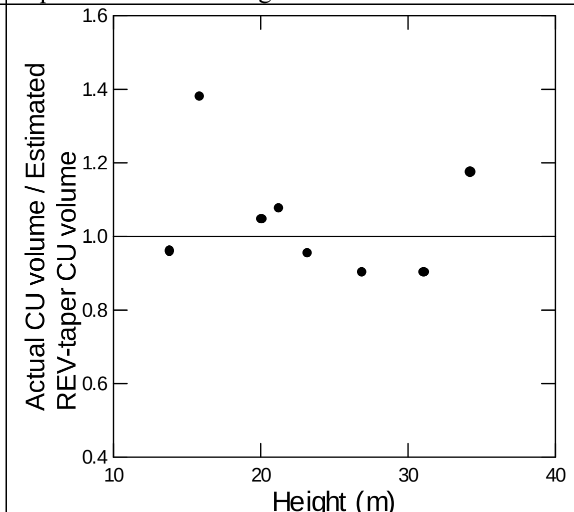


Figure D-57: Revenue Branch FIZ-based taper equation bias vs tree height.

Live Immature (all species) Stratum:

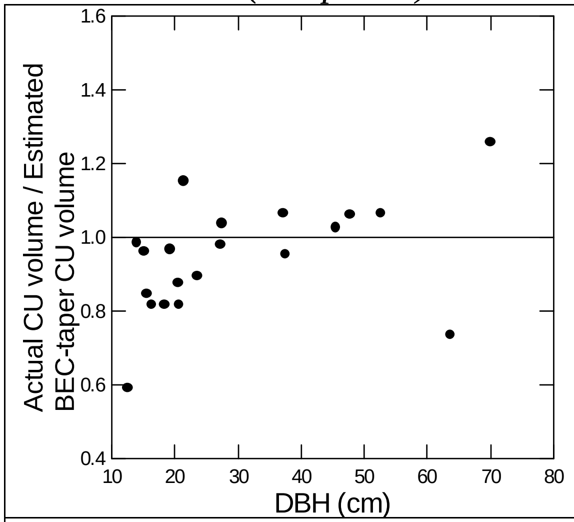


Fig. D-58: BEC-based taper equation bias vs dbh.

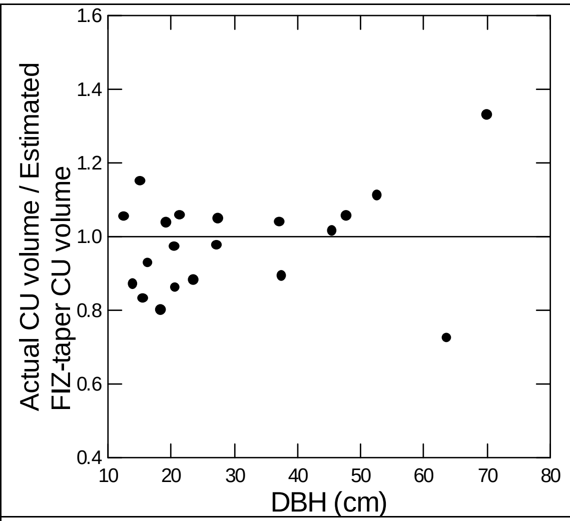


Figure D-59: FIZ-based taper equation bias vs dbh.

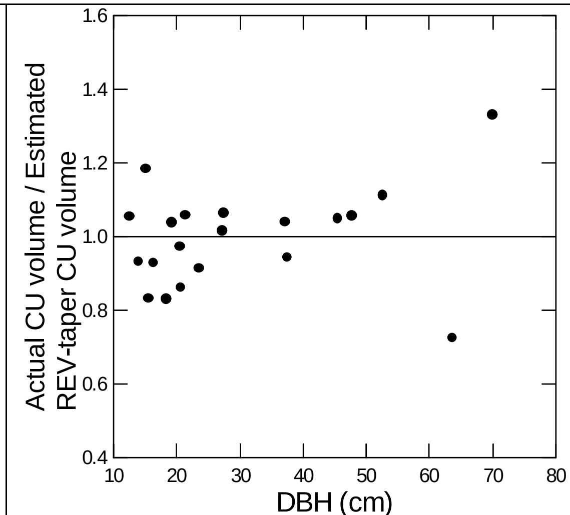


Figure D-60: Revenue Branch FIZ-based taper equation bias vs dbh.

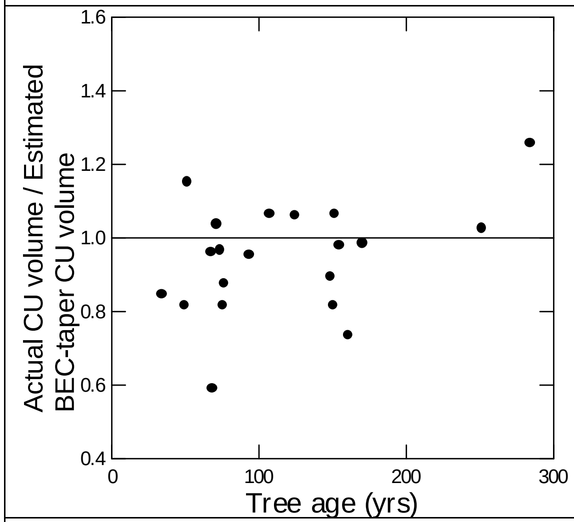


Figure D-61: BEC-based taper equation bias vs tree age.

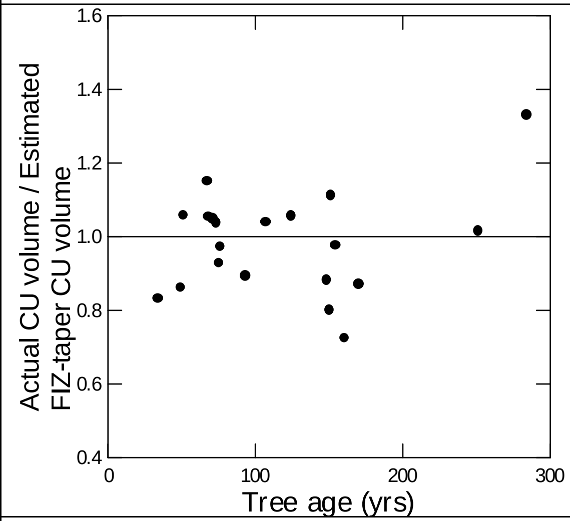


Figure D-62: FIZ-based taper equation bias vs tree age.

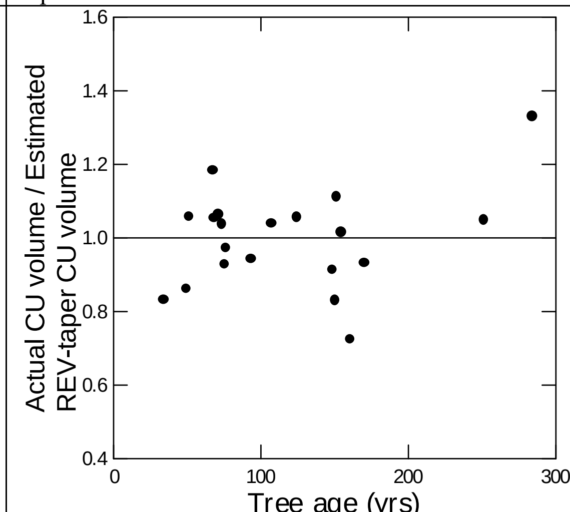


Figure D-63: Revenue Branch FIZ-based taper equation bias vs tree age.

Live Immature (all species) Stratum (cont'd):

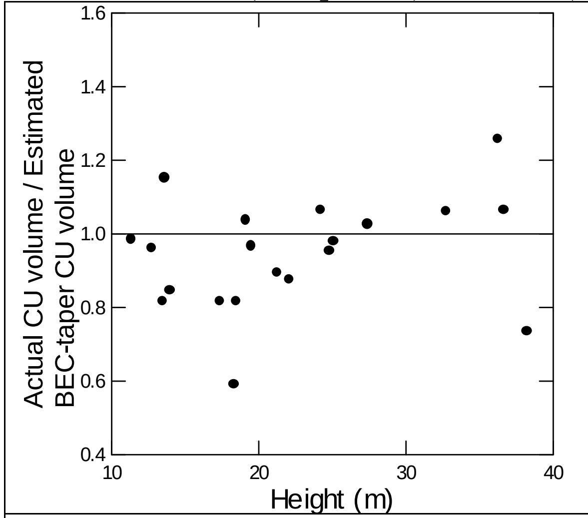


Figure D-64: BEC-based taper equation bias vs tree height.

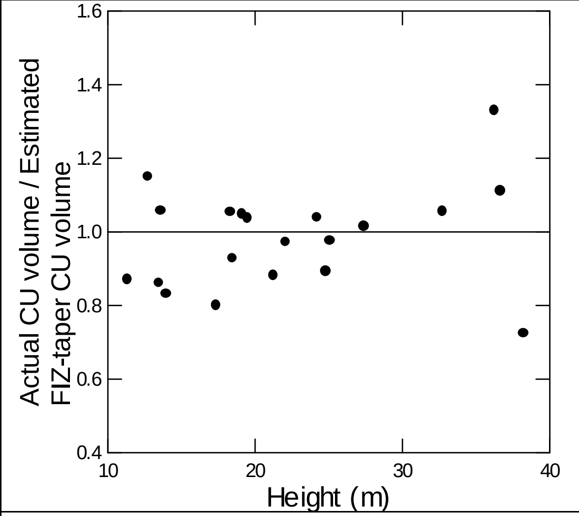


Figure D-65: FIZ-based taper equation bias vs tree height.

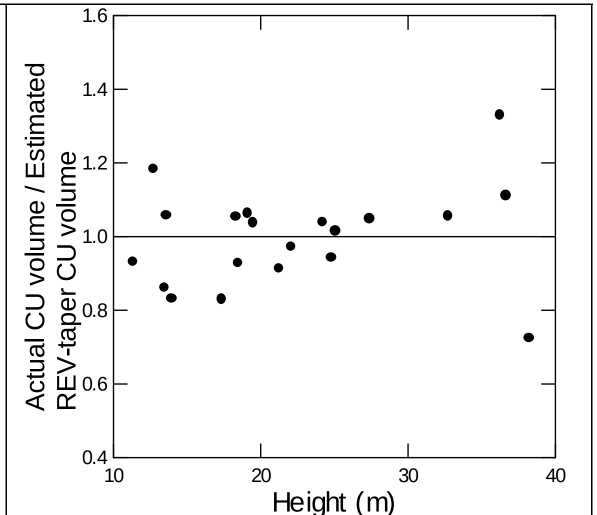


Figure D-66: Revenue Branch FIZ-based taper equation bias vs tree height.

Dead (all species) Stratum:

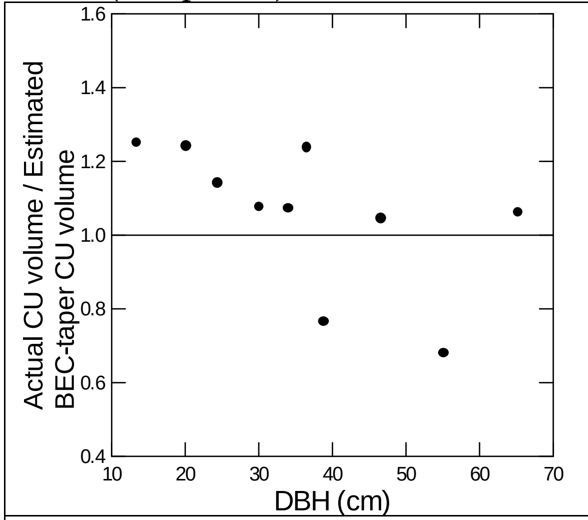


Fig. D-67: BEC-based taper equation bias vs dbh.

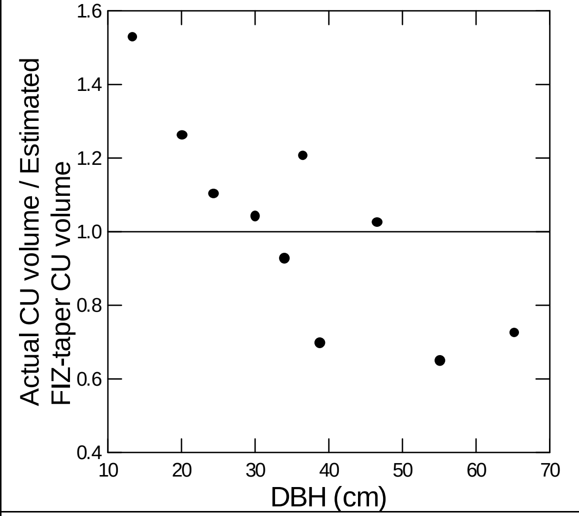


Figure D-68: FIZ-based taper equation bias vs dbh.

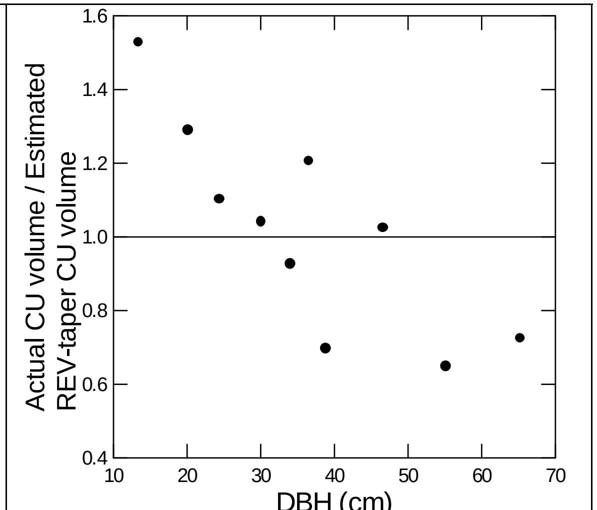


Figure D-69: Revenue Branch FIZ-based taper equation bias vs dbh.

Dead (all species) Stratum (cont'd):

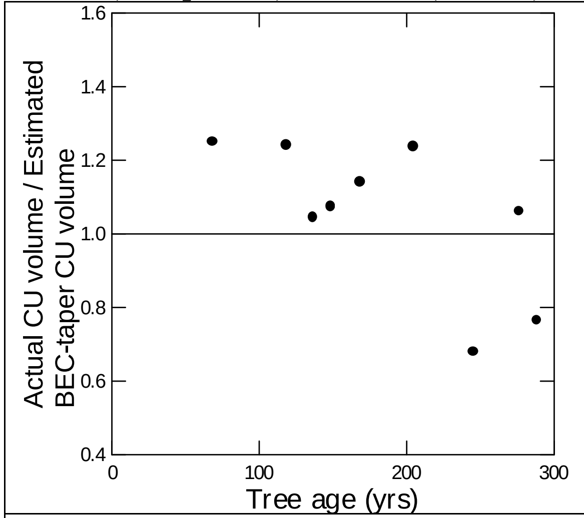


Figure D-70: BEC-based taper equation bias vs tree age.

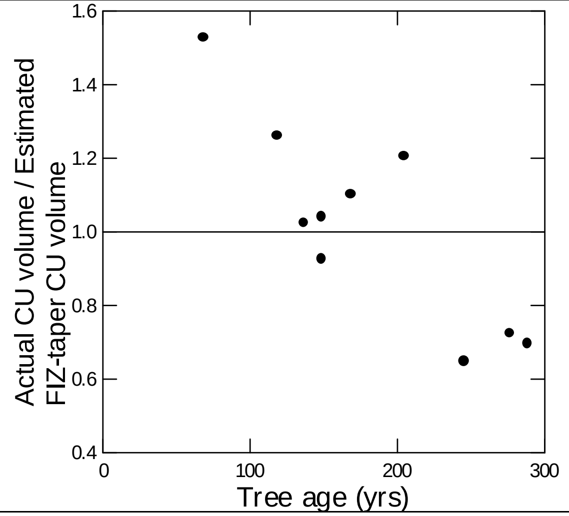


Figure D-71: FIZ-based taper equation bias vs tree age.

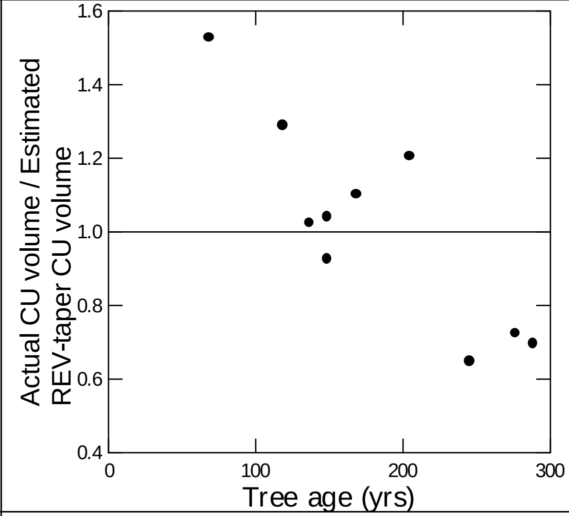


Figure D-72: Revenue Branch FIZ-based taper equation bias vs tree age.

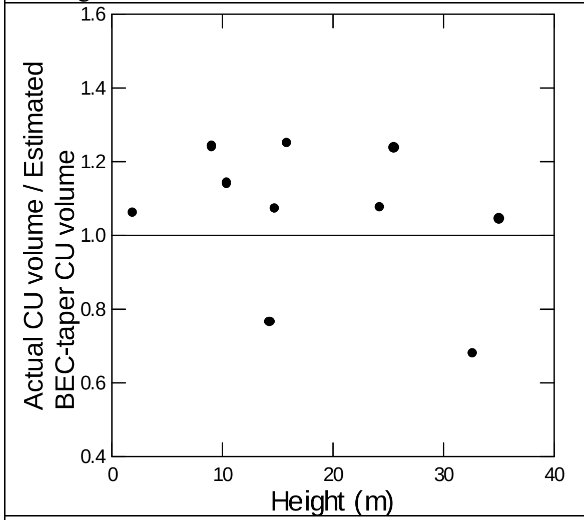


Figure D-73: BEC-based taper equation bias vs tree height.

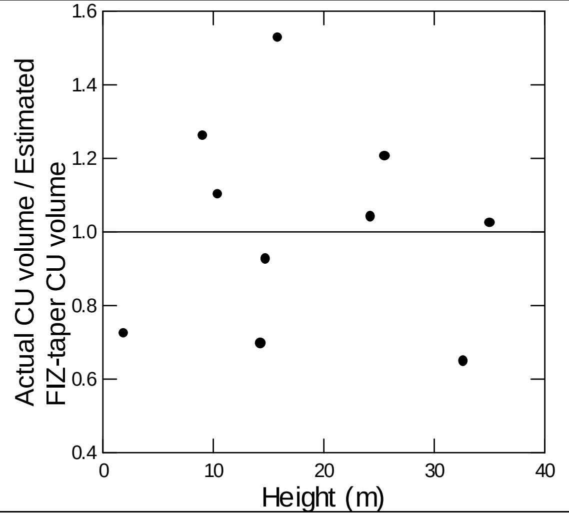


Figure D-74: FIZ-based taper equation bias vs tree height.

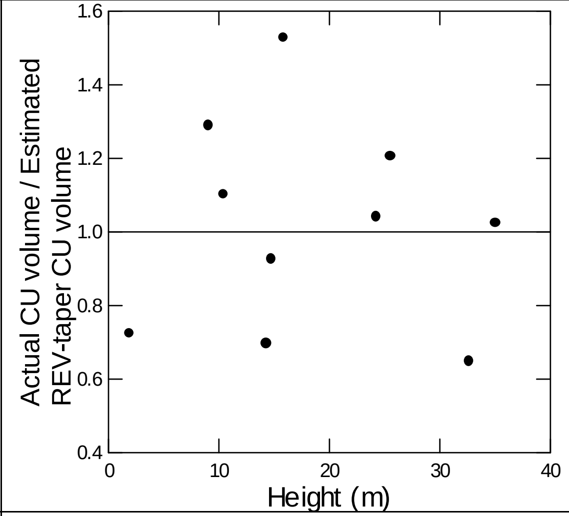


Figure D-75: Revenue Branch FIZ-based taper equation bias vs tree height.

9. APPENDIX E: DECAY AND WASTE 2 BIAS GRAPHS BY RISK GROUP & STRATUM

NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.

Live Mature Balsam Stratum

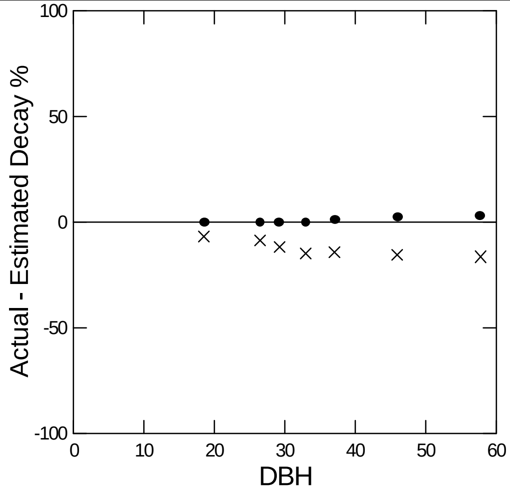


Fig. E-1: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

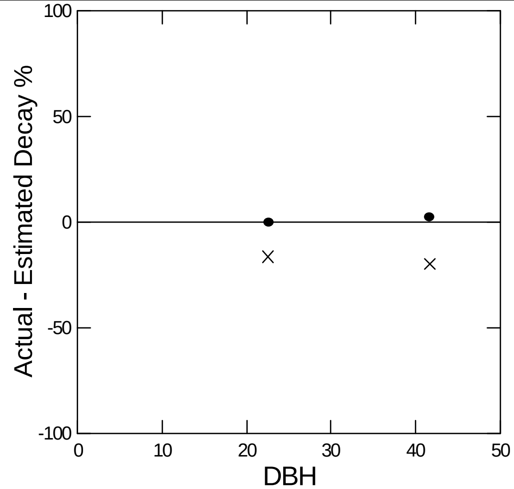


Fig. E-2: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-3: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

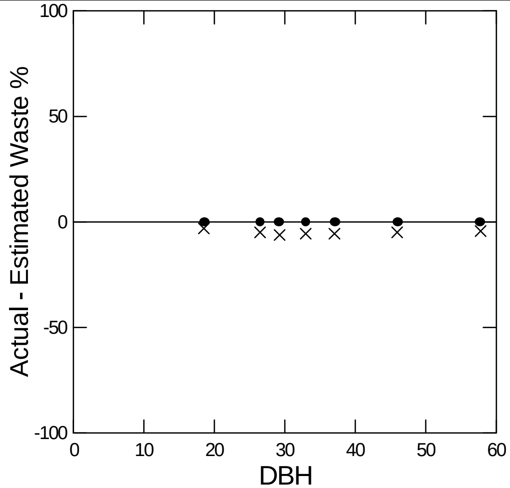


Fig. E-4: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

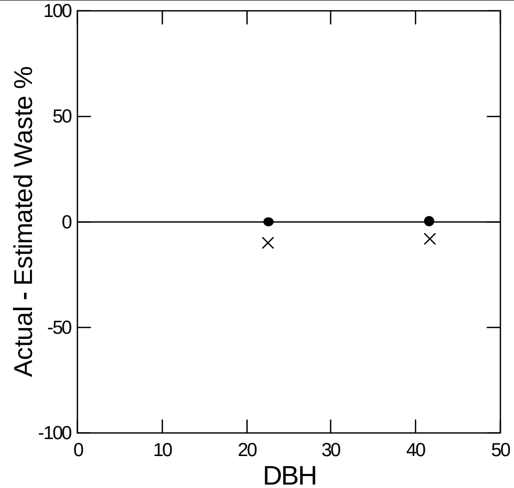


Fig. E-5: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-6: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Mature Cedar Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

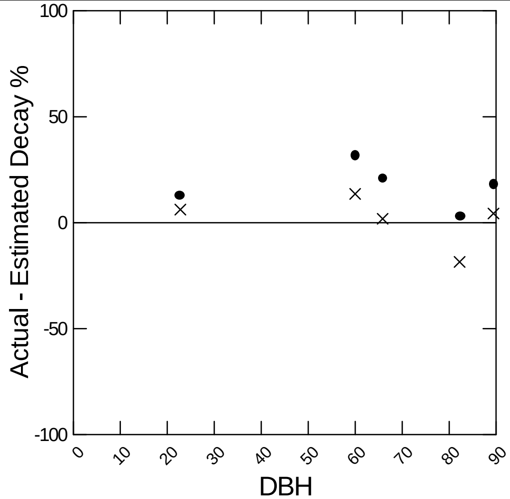


Fig. E-7: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

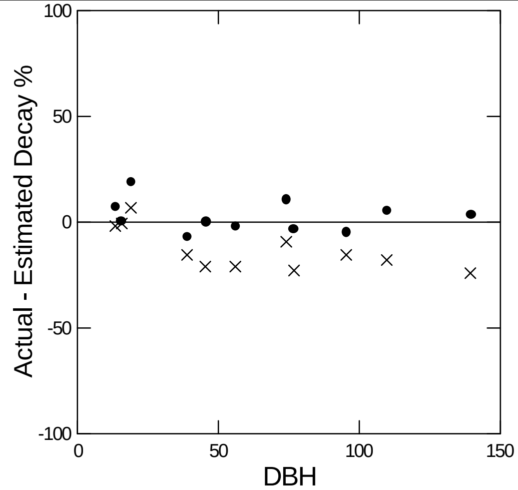


Fig. E-8: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-9: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

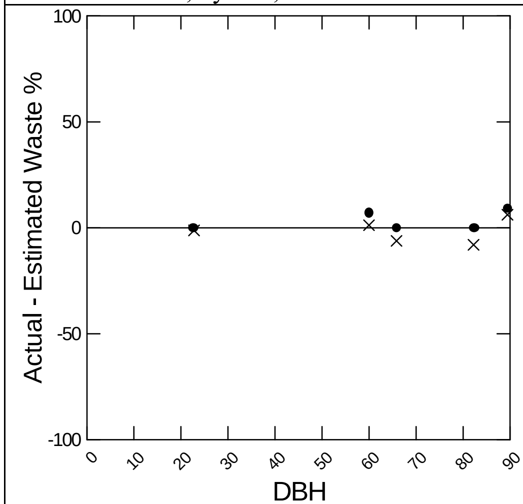


Fig. E-10: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

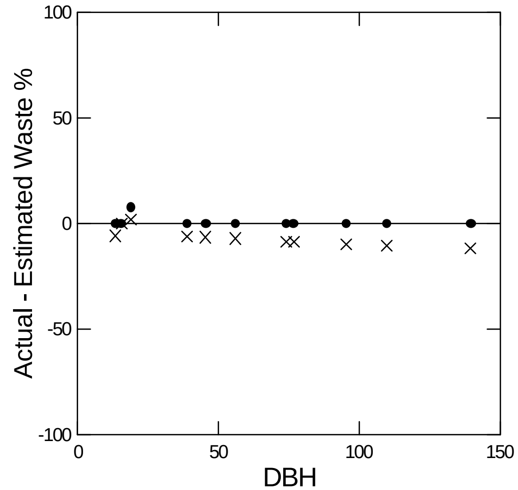


Fig. E-11: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-12: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Mature Douglas-fir Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

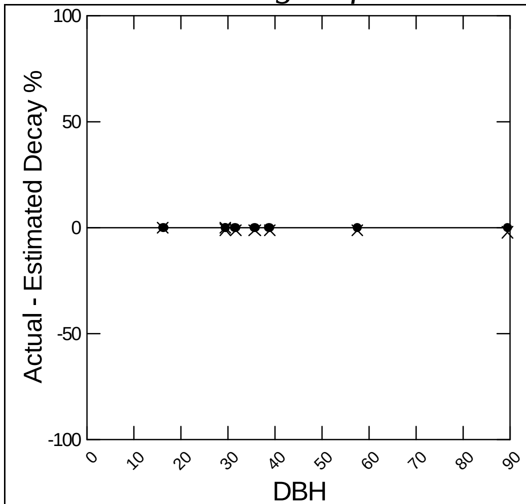


Fig. E-13: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

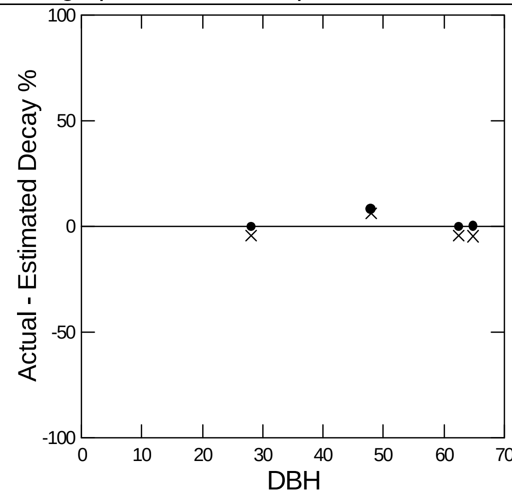


Fig. E-14: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-15: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

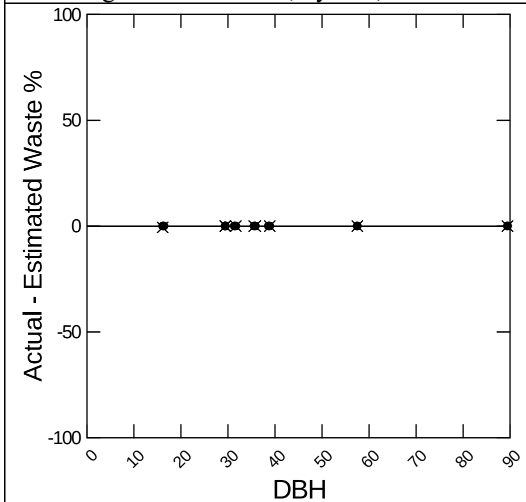


Fig. E-16: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

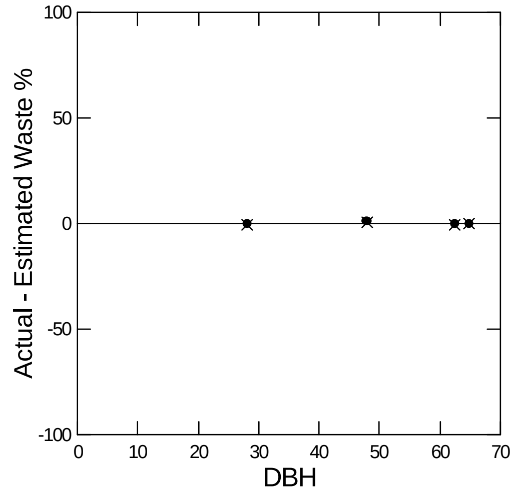


Fig. E-17: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-18: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Mature Hemlock Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

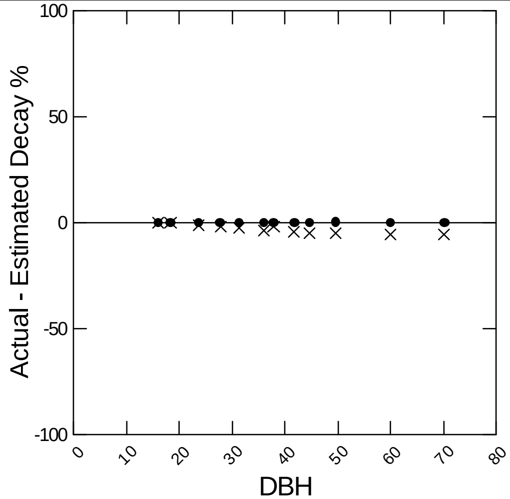


Fig. E-19: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

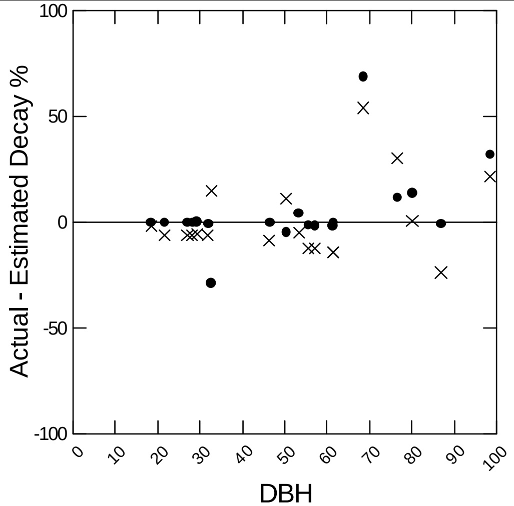


Fig. E-20: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

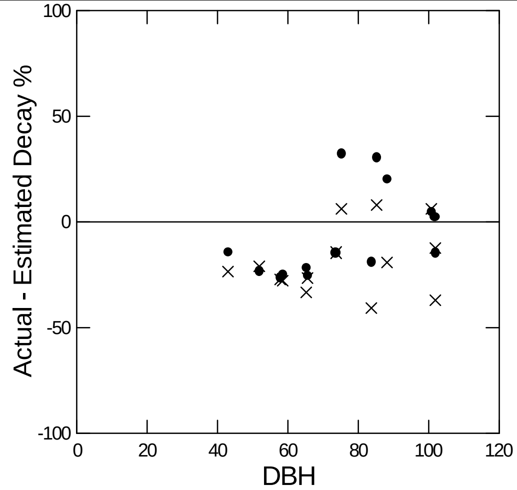


Fig. E-21: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

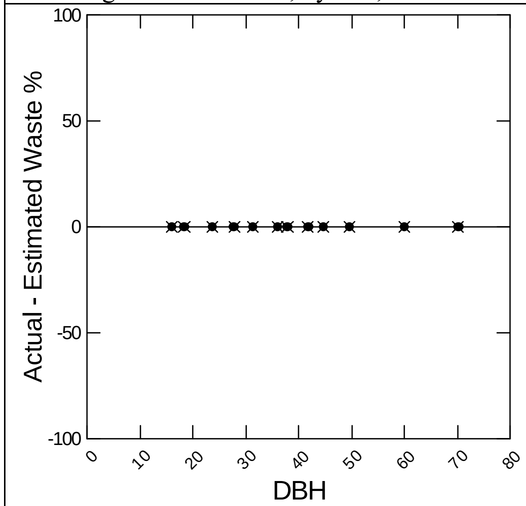


Fig. E-22: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

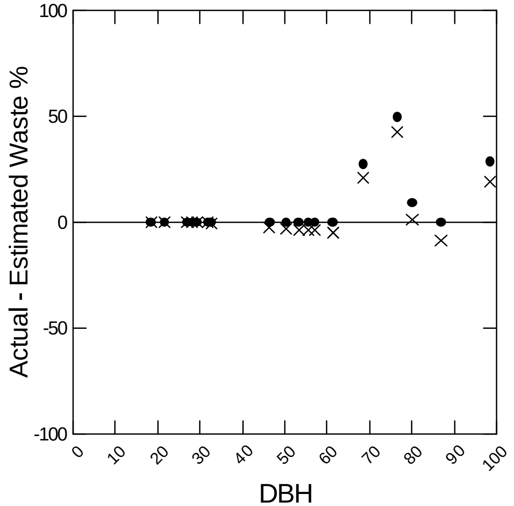


Fig. E-23: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

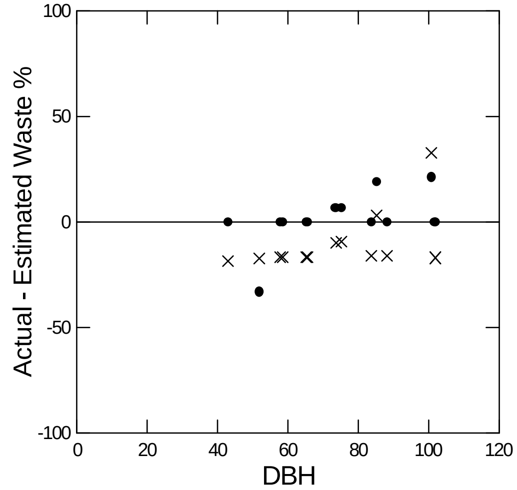


Fig. E-24: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Mature Spruce Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

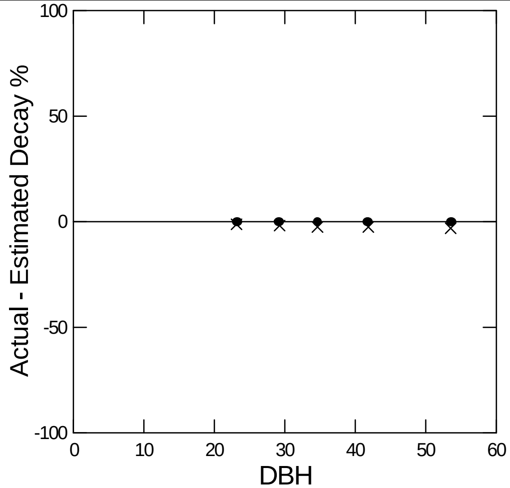


Fig. E-25: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

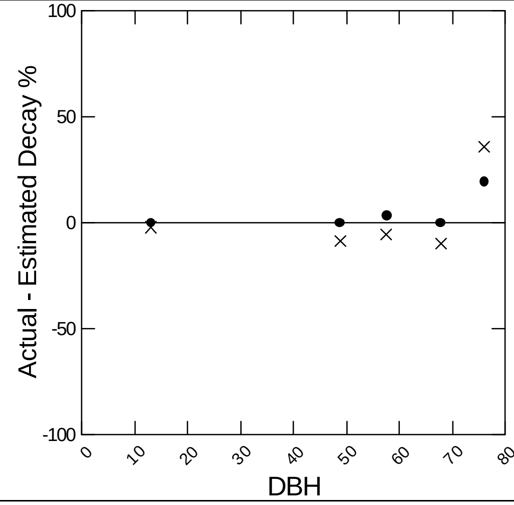


Fig. E-26: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-27: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

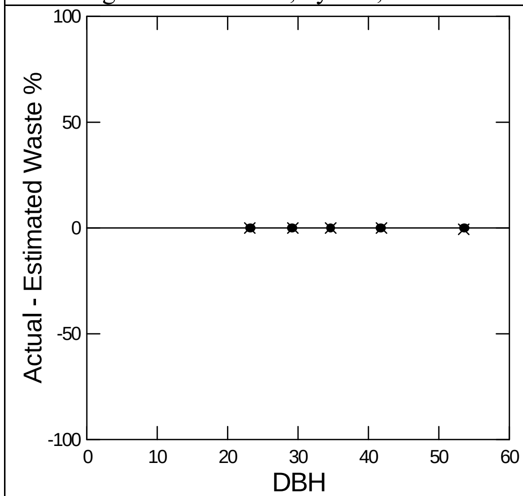


Fig. E-28: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

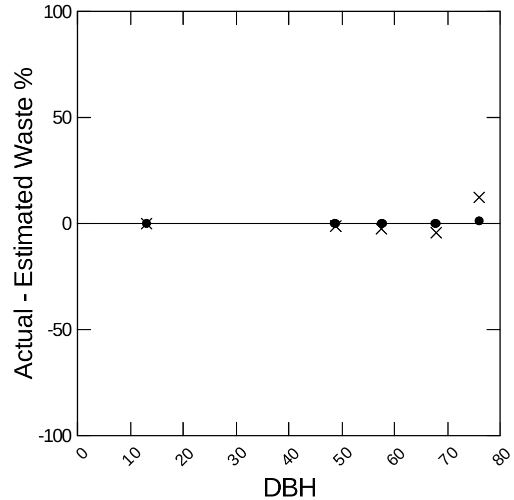


Fig. E-29: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-30: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Mature "Other species" Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

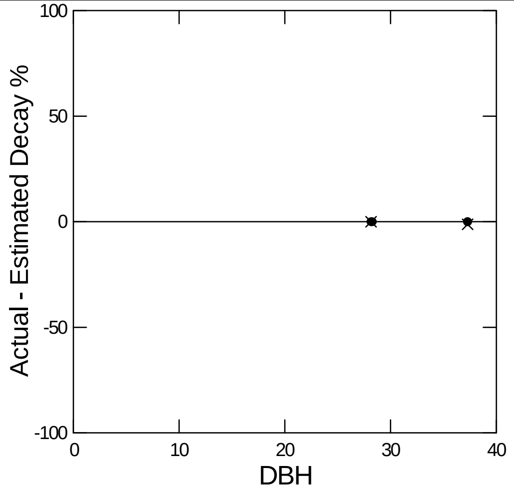


Fig. E-31: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

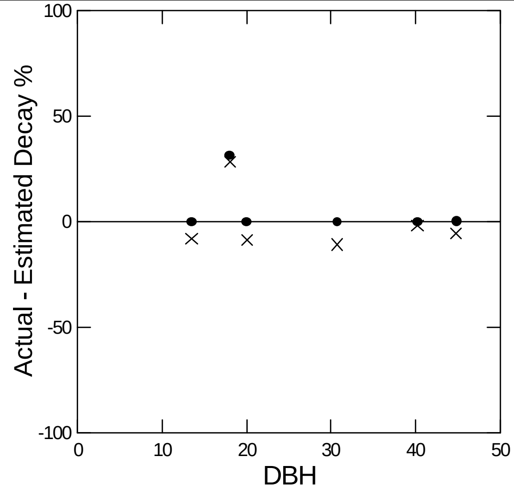


Fig. E-32: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-33: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

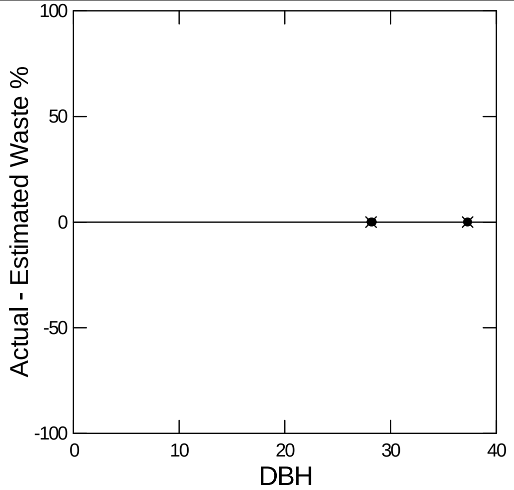


Fig. E-34: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

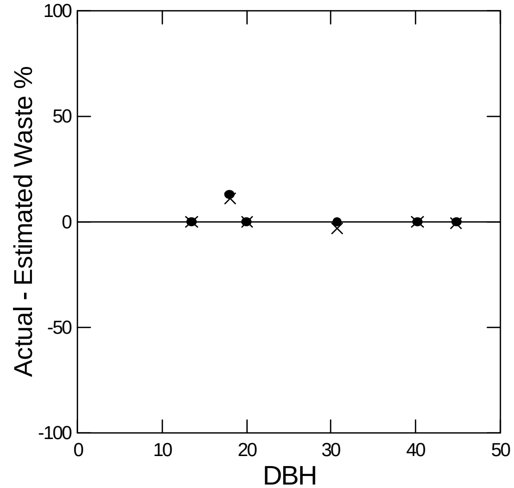


Fig. E-35: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-36: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Live Immature (all species) Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

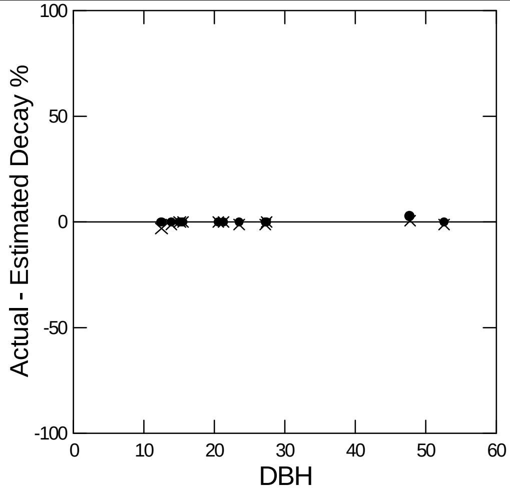


Fig. E-37: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

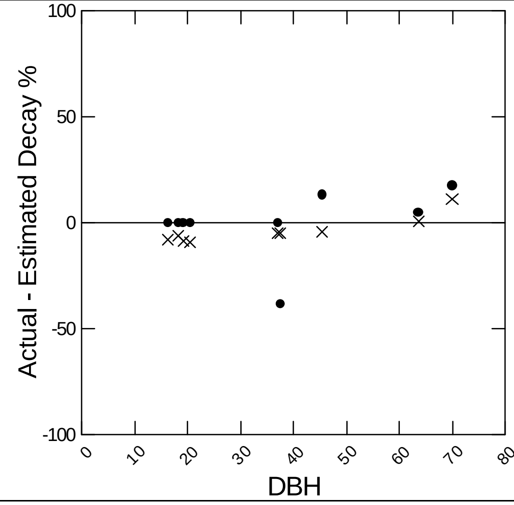


Fig. E-38: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-39: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

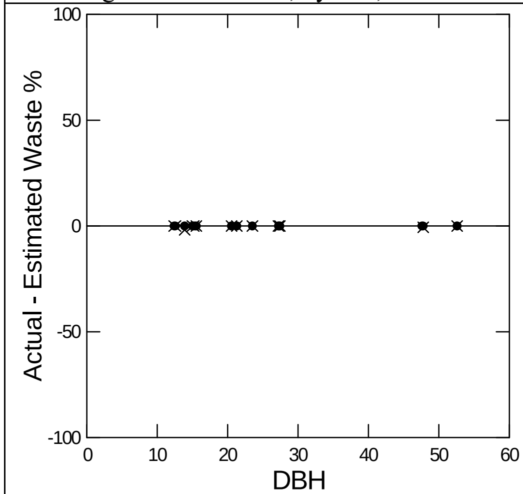


Fig. E-40: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

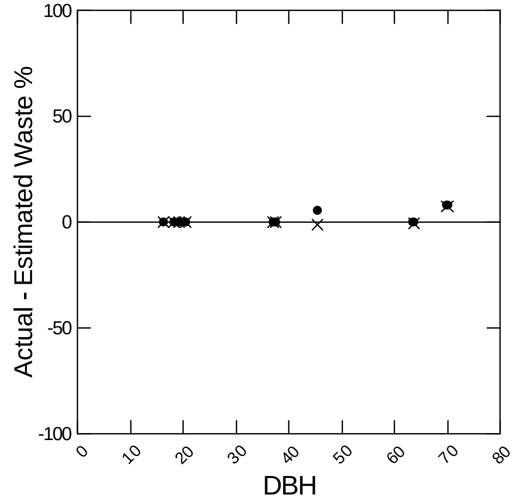


Fig. E-41: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

no sample trees

Fig. E-42: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

Dead (all species) Stratum *(NOTE: In the graphs below, •'s represent net factoring bias and ×'s represent loss factor bias.)*

no sample trees

Fig. E-43: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 1.

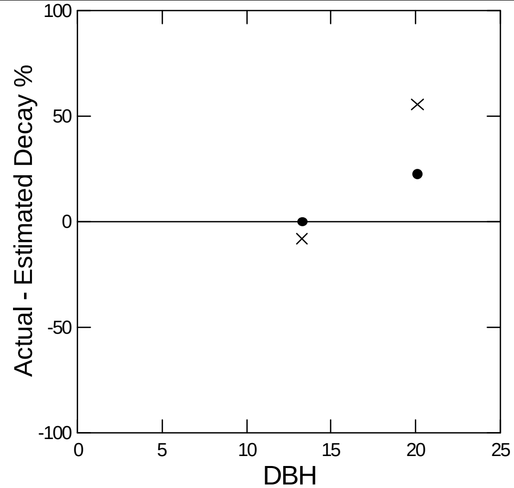


Fig. E-44: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 2.

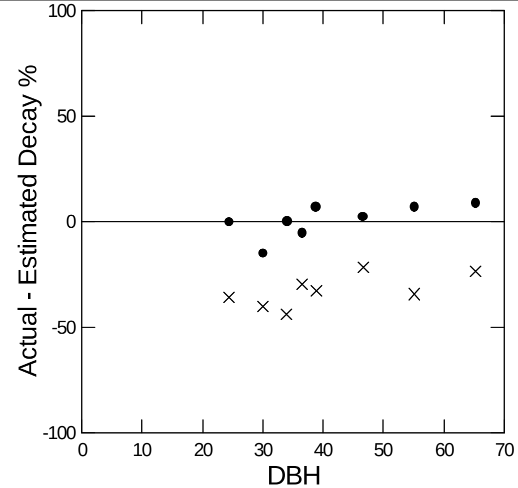


Fig. E-45: Bias in estimates of decay % for net factoring and loss factors, by dbh, for RISK GROUP 3.

no sample trees

Fig. E-46: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 1.

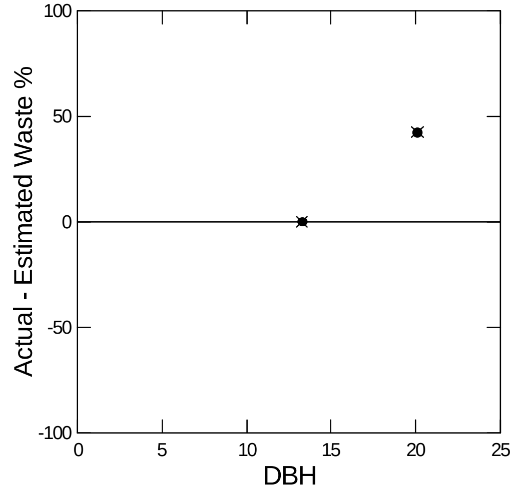


Fig. E-47: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 2.

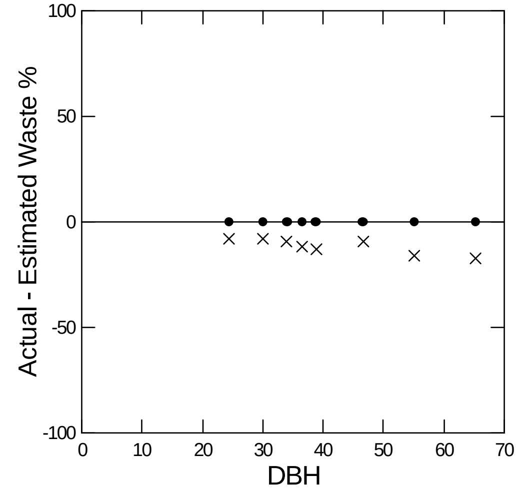


Fig. E-48: Bias in estimates of waste2 % for net factoring and loss factors, by dbh, for RISK GROUP 3.

10. APPENDIX F: LOSS FACTOR DECAY ESTIMATION BIAS BY RISK INDICATOR[37] FOR MATURE HEMLOCK TREES

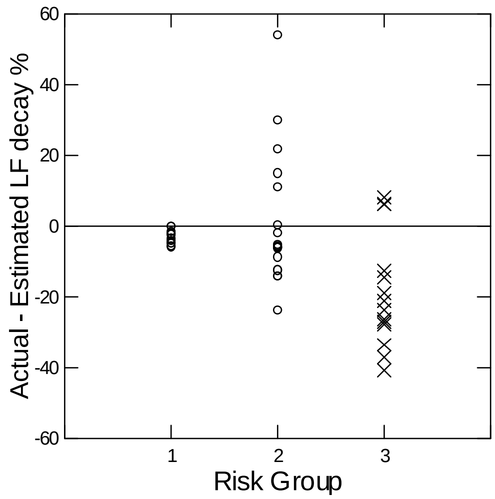


Fig F-1: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***CONK***; ○'s represent absence of conk.

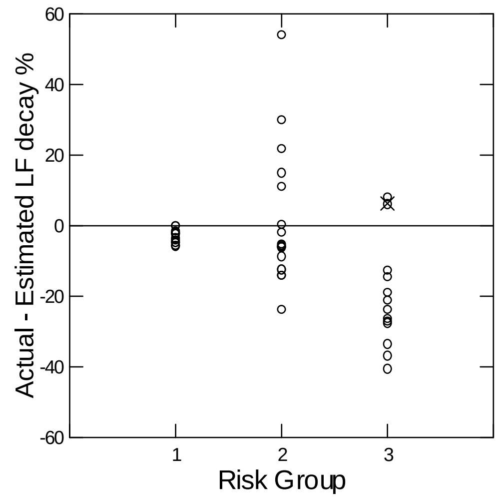


Fig F-2: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***BLIND CONK***; ○'s represent absence of blind conk.

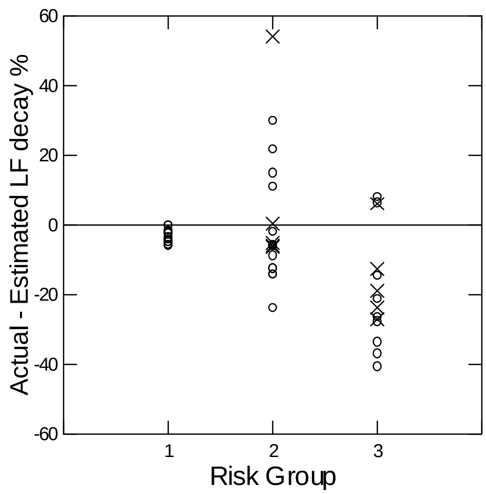


Fig F-3: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***SCAR***; ○'s represent absence of scar.

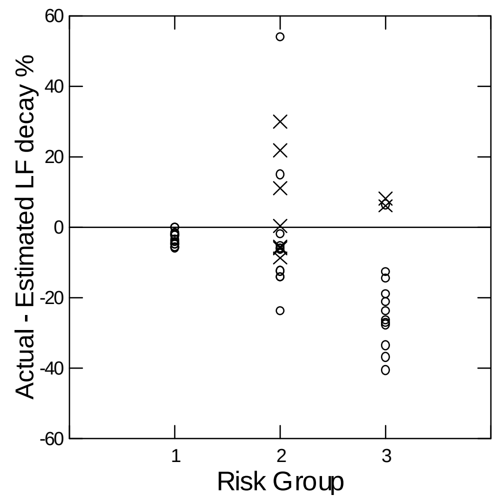


Fig F-4: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***FORK/CROOK***; ○'s represent absence of fork/crook.

[37] Pathological indicators from standing trees

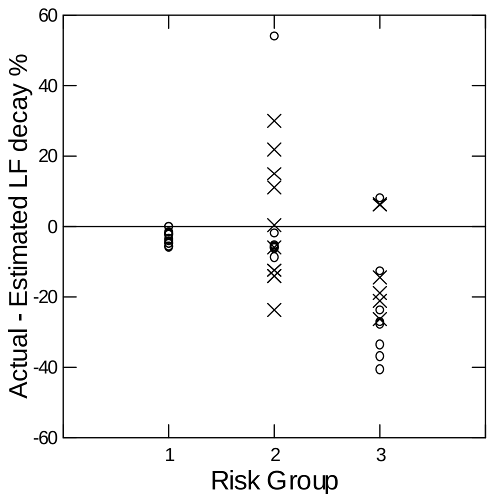


Fig F-5: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***FROST CRACK***; ○'s represent absence of frost crack.

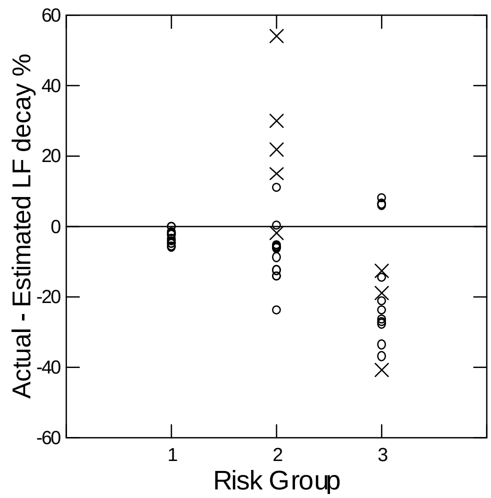


Fig F-6: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***DEAD/BROKEN TOP***; ○'s represent absence of dead/broken top.

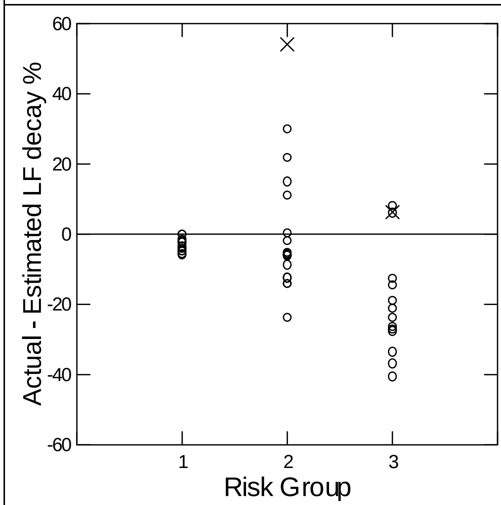


Fig F-7: Actual decay % minus loss factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***ROTTEN BRANCH***; ○'s represent absence of rotten branch.

11. APPENDIX G: NET FACTORING DECAY ESTIMATION BIAS BY RISK INDICATOR[38] FOR MATURE HEMLOCK TREES

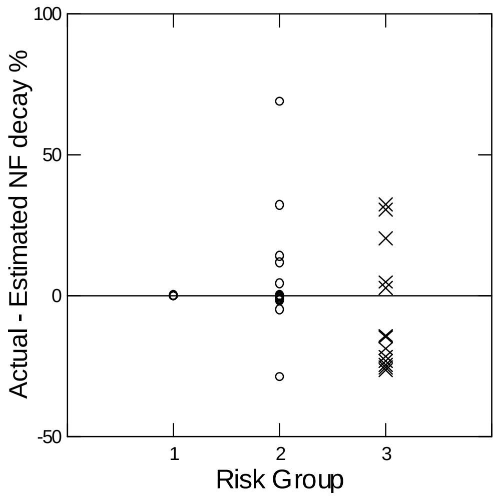


Fig G-1: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***CONK***; ○'s represent absence of conk.

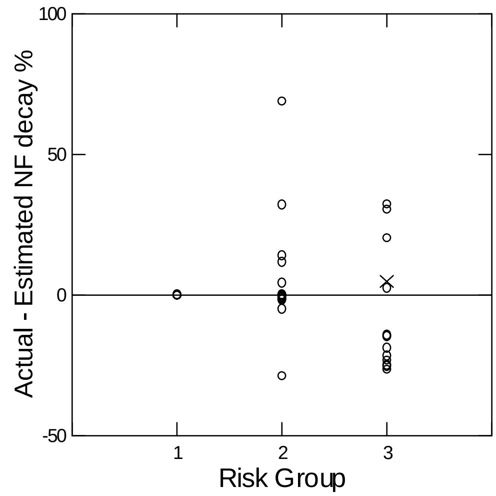


Fig G-2: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***BLIND CONK***; ○'s represent absence of blind conk.

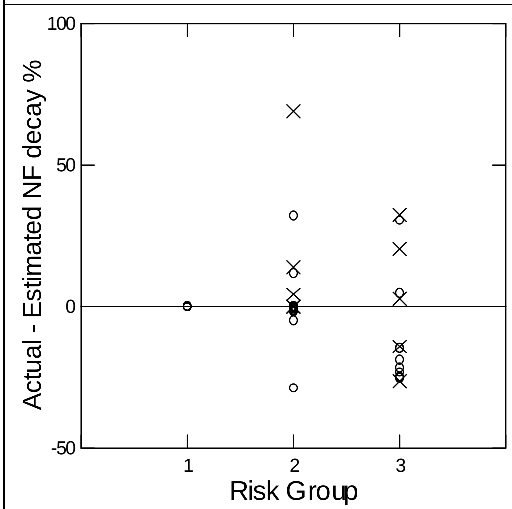


Fig G-3: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***SCAR***; ○'s represent absence of scar.

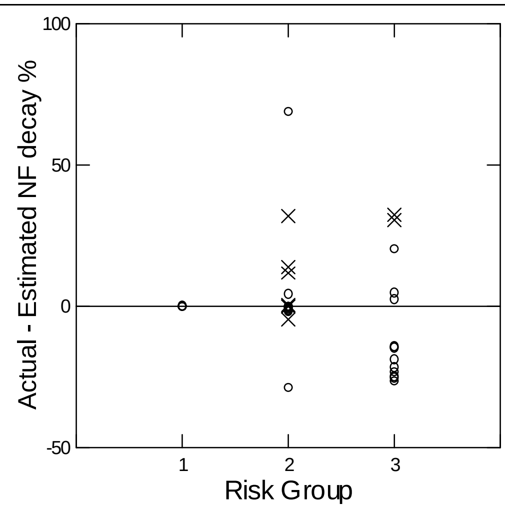


Fig G-4: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***FORK/CROOK***; ○'s represent absence of fork/crook.

[38] Pathological indicators from standing trees

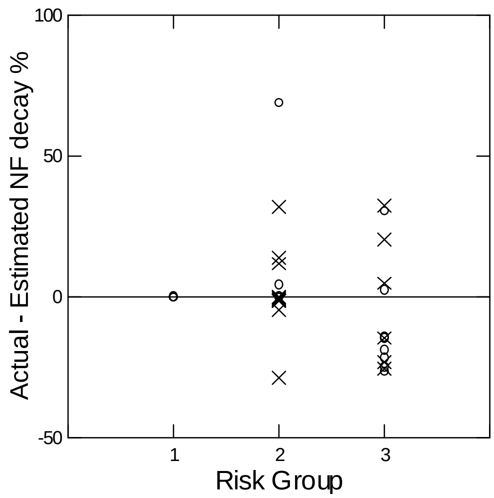


Fig G-5: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***FROST CRACK***; ○'s represent absence of frost crack.

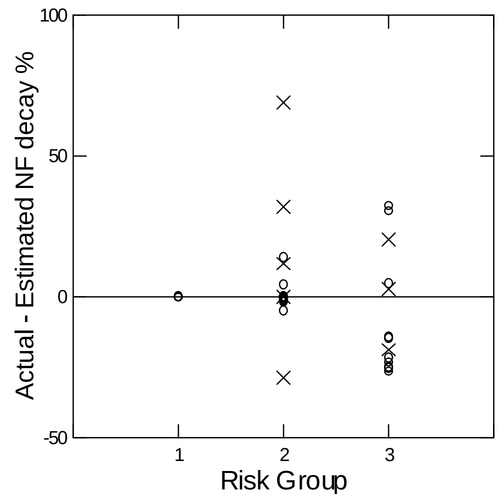


Fig G-6: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***DEAD/BROKEN TOP***; ○'s represent absence of dead/broken top.

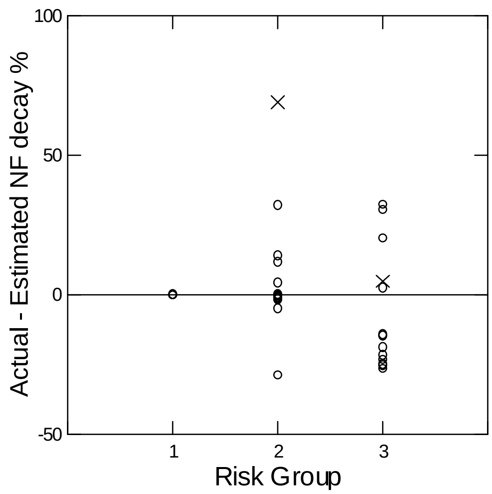


Fig G-7: Actual decay % minus net factor estimate of decay %, by risk group. NOTE: ×'s represent trees with ***ROTTEN BRANCH***; ○'s represent absence of rotten branch.