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CONSIDERATIONS WHEN SAMPLING SPRUCE BUDWORM EGG MASSES ON BALSAM FIR AND WHITE SPRUCE IN THE LAKE STATES: LOW POPULATION LEVELS[1]

Gary W. Fowler[2] and Gary A. Simmons[3]

ABSTRACT

One cluster each of balsam fir, *Abies balsamea*, and white spruce, *Picea glauca*, trees was chosen from each of five stands of spruce-fir in Michigan's Upper Peninsula. The foliage surface area and the number of new egg masses of the spruce budworm, *Choristoneura fumiferana*, were determined for each branch and the top of each tree. The effects, in terms of the bias and the variance of the estimator, of sampling in different parts of the tree and with various size branches were determined. Factors that the sampler should consider in developing sampling plans to estimate spruce budworm egg mass densities in mixed spruce-fir stands were identified. Egg mass density and its per branch variance may be considerably higher in white spruce than in balsam fir. Sampling whole feasible branches at mid-crown yielded, in general, the most precise and accurate estimates of tree egg mass density.

Little is known about sampling mixed spruce-fir stands to estimate spruce budworm, *Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae), egg mass density. The objectives of this study were to (1) examine the differences in egg mass density between white spruce, *Picea glauca* (Meunchhausen) Voss, and balsam fir, *Abies balsamea* (L.) Miller, trees in mixed stands; (2) determine the effects of sampling different sampling units from various portions of the tree crown by examining the bias and variance of the estimator; and (3) identify important considerations for developing egg mass density sampling plans in mixed spruce-fir stands.

METHODS AND MATERIALS

The data used in this paper are part of a spruce budworm egg mass density sampling study conducted in the Upper Peninsula of Michigan during the summers of 1979 and 1980. The entire study was described by Fowler and Simmons (1982) and Simmons and Fowler (1982).

In each of five clusters of trees, two balsam fir and two white spruce trees were selected for complete enumeration. Two additional balsam fir trees were enumerated for one cluster, yielding a total of 12 balsam fir and 10 white spruce "every branch trees." Trees were selected in such a way as to yield low egg mass population densities. In each cluster, the following criteria were used to select individual trees: (a) overtopped by hardwoods; (b) least defoliation and healthiest tops; (c) proximity to spruce-fir pocket; (d) from 30 to 60 feet (9 to 18 m) tall with no dead tops; (e) crown full enough so branches feasible for sampling could be clipped from mid-crown with pole pruners.

The number of new egg masses and foliage surface area were determined for each branch and the top, where branches were less than 70 cm long, of each tree. Each branch

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was classified as belonging to the lower-, mid-, or upper-crown of the tree. This was determined by visually dividing the live crown vertically into thirds. The upper-crown included the branches of the upper third and the top of the tree. The top of the tree consisted of that portion of the upper crown containing branches less than 70 cm in length. All branches in the mid-crown that were judged to be feasible for sampling with a pole pruner were called "feasible branches."

One of the balsam fir and one of the white spruce "every branch trees" with full crowns from each cluster were designated "sampling scheme trees." Samplers tend to select such trees for ease of sampling. One additional balsam fir tree from one cluster was also designated a "sampling scheme tree," yielding a total of six balsam fir and five white spruce trees. For all branches in the mid-crown considered to be "feasible branches," the number of new egg masses and foliage surface area were determined for the first 40, 50, 60, and 70 cm of that branch from the tip.

RESULTS AND DISCUSSION

Information obtained from the "every branch trees" will be referred to as the every branch dataset; information obtained from the "sampling scheme trees" will be referred to as the sampling scheme dataset. All means related to a given dataset, unless otherwise stated, are arithmetic means on a per tree basis. In other words, the analysis centers on the average tree of a given species.

Errors Due to Sampling Only a Portion of the Tree

We were interested in estimating egg mass density for an entire tree. This is the total number of new egg masses divided by the total foliage surface area of the tree and is expressed as the number of egg masses per 1000 cm^2 of foliage surface area (TEMD). We examined the effects of sampling only a portion of the tree. The egg mass density for each tree portion was determined by dividing the number of new egg masses by the foliage surface area found on that portion (surface area method). This egg mass density was then compared to TEMD. Absolute error is the difference between the density of the tree portion and TEMD, while relative error is the absolute error divided by TEMD, multiplied by 100.

Every branch dataset. The average egg mass densities for the every branch dataset are shown in Table 1. While there was considerable tree-to-tree and cluster-to-cluster variation, there were some trends evident.

For balsam fir, sampling in the tree WOT (without top), lower-crown, mid-crown, upper-crown WOT, upper-crown WT (with top) and feasible branches yielded relative errors of −8.9, −76.8, −2.7, 117.9, 151.8, and 9.8%, respectively. For white spruce,

Table 1. Average egg mass density (no. egg masses per 1000 cm^2, surface area method) and standard deviation ( ) for the 12 balsam fir (BF) and 10 white spruce (WS) trees in the every branch dataset.

Species	Feasible Branches	Infeasible Branches	All Branches (Tree WOT)	Lower Crown	Middle Crown	Upper Crown WOT[a]	Upper Crown WT[b]	Tree WT (TEMD)
BF	0.123 (0.123)	0.098 (0.098)	0.102 (0.092)	0.026 (0.040)	0.109 (0.117)	0.244 (0.244)	0.282 (0.282)	0.112 (0.107)
WS	0.384 (0.369)	0.320 (0.302)	0.334 (0.309)	0.122 (0.094)	0.310 (0.269)	0.608 (0.544)	0.608 (0.525)	0.341 (0.310)

[a]Without Top
[b]With Top

sampling in the same tree parts yielded relative errors of −2.1, −64.2, −9.1, 78.3, 78.3, and 12.6%, respectively.

Tree WT egg mass density (TEMD) was somewhat underestimated when sampling the tree WOT with the relative error for balsam fir being about 4 times that for white spruce. TEMD was greatly underestimated when sampling the lower-crown with the relative error for balsam fir being somewhat greater than that for white spruce. Sampling at mid-crown somewhat underestimated tree density with the relative error for white spruce being about 3 times that for balsam fir.

Sampling in the upper-crown WOT and WT greatly overestimated TEMD with the relative error for balsam fir being considerably larger than that for white spruce. Density in the tree top for balsam fir was considerably higher than that in the branches of the upper-crown while this difference was negligible for white spruce. TEMD was over-estimated about 10% for both species when sampling feasible branches. Mid-crown density was over-estimated when sampling feasible branches with the relative error being 12.8 and 23.9% for balsam fir and white spruce, respectively (Table 1).

Table 1 shows that white spruce egg mass density was about 3 times that for balsam fir for TEMD, sampling the tree WOT and at mid-crown yielded underestimates of TEMD less than 10% for both species, and sampling feasible branches yielded overestimates of TEMD around 10% for both species. *Results indicate that if only a small portion of the tree is to be sampled mid-crown or feasible branches should be used for both species.*

Sampling Scheme Dataset. The average egg mass densities for the sampling scheme dataset are shown in Table 2. We not only examined the effects of sampling the tree WOT, mid-crown, and whole feasible branches but also the effects of sampling the first 40, 50, 60, and 70 cm of feasible branches from the branch tip. Once again there was considerable tree-to-tree and cluster-to-cluster variation with some trends evident.

For balsam fir, sampling in the tree WOT, mid-crown, and whole, 70, 60, 50, and 40-cm feasible branches yielded relative errors of −5.8, 22.1, 55.8, 169.8, 170.9, 196.5, and 179.1%, respectively. For white spruce, sampling in the same tree parts yielded relative errors of −3.2, −10.3, 14.0, 56.4, 67.7, 82.0, and 105.9%, respectively.

TEMD was somewhat underestimated when sampling the tree WOT with the relative error for balsam fir approximately twice that for white spruce. Sampling at mid-crown overestimated TEMD for balsam fir and underestimated TEMD for white spruce, respectively, with the absolute relative error for balsam fir being approximately twice that of white spruce.

Sampling whole feasible branches considerably overestimated (55.8%) and somewhat overestimated (14.0%) TEMD density for balsam fir and white spruce, respectively. Mid-crown density was overestimated when sampling whole feasible branches with the relative error being 27.6 and 27.2% for balsam fir and white spruce, respectively (Table 2).

In general, tree density was increasingly overestimated as feasible branch size de-

Table 2. Average egg mass density (no. egg masses per 1000 cm^2, surface area method) and standard deviation ( ) for the six balsam fir (BF) and five white spruce (WS) trees in the sampling scheme dataset.

	Feasible Branches					Middle	Tree	
Species	Whole	70 cm	60 cm	50 cm	40 cm	Crown	WOT[a]	WT[b]
BF	0.134 (0.154)	0.232 (0.284)	0.233 (0.313)	0.255 (0.311)	0.240 (0.295)	0.105 (0.112)	0.081 (0.072)	0.086 (0.073)
WS	0.463 (0.376)	0.635 (0.488)	0.681 (0.511)	0.739 (0.585)	0.836 (0.630)	0.364 (0.268)	0.393 (0.308)	0.406 (0.303)

[a]Without Top
[b]With Top—TEMD

creased from whole to 40-cm branches with the relative errors for balsam fir being, on the average, over twice that for white spruce.

Table 2 shows that white spruce egg mass density was 4.7 times that for balsam fir for TEMD, sampling the tree WOT somewhat underestimated TEMD for both species, sampling at mid-crown overestimated TEMD for balsam fir and underestimated TEMD for white spruce, sampling feasible branches yielded overestimates of TEMD around 27% for both species, and smaller branch sizes yielded larger relative errors for both species. *Results indicate that if a feasible branch is to be the sampling unit, whole branches should be used for both species.*

Errors Due to Using the Branch as a Sampling Unit

Once again we were interested in estimating TEMD. We examined the effects of using the per branch average of egg mass density of various portions of the tree on the estimate of TEMD. First, the number of new egg masses per unit of foliage surface area was determined for each branch. Then the average of all branches in the tree portion of interest (per branch method) was determined. Egg mass densities were once again expressed on a per 1000 cm^2 basis. The branch is the sampling unit, and estimates of TEMD based on the per branch method are biased because foliage surface area is not the same for each branch. Because foliage surface areas are not known prior to sampling, unbiased estimates are not possible.

The per branch egg mass densities for various portions of the tree were compared with TEMD. The variances of per branch egg mass density for various tree parts were compared with that for the tree WOT, the population parameter of interest. Absolute and relative errors for density are as described earlier. For the variance, absolute error is the difference between the variance of the tree portion and the variance of the tree WOT, while relative error is the absolute error divided by the tree WOT variance, multiplied by 100.

The population variance ($V(\bar{x})$) and mean square error ($MSE(\bar{x})$) of the sample mean were calculated for various tree portions, along with the precision and accuracy %, with sample sizes of 2, 5, and 10 branches, where

$$V(\bar{x}) = V(X)/n$$

$$MSE(\bar{x}) = V(\bar{x}) + B^2$$

$V(X)$ = per branch variance of egg mass density for tree portion

n = sample size

B = bias (the absolute error for the tree portion)

$$\text{precision \%} = (\sqrt{V(\bar{x})}/\mu)100$$

$$\text{accuracy \%} = (\sqrt{MSE(\bar{x})}/\mu)100$$

μ = tree WT egg mass density-surface area method (TEMD)

Fowler and Witter (1982) provided a detailed examination of the accuracy and precision of insect density and impact estimates.

Every branch dataset. The average per branch egg mass densities for the every branch dataset are shown in Table 3 for various tree parts. As with the surface area method, there was considerable tree-to-tree and cluster-to-cluster variation.

Egg mass density calculated using the per branch method varied somewhat from that calculated using the surface area method (Tables 1 and 3) for the various tree parts. Using the density based on the surface area method for a given tree part as the parameter of

Table 3. Average egg mass density (no. egg masses per 1000 cm^2, per branch method) and standard deviation ( ) for the 12 balsam fir (BF) and 10 white spruce (WS) trees in the every branch dataset.

Species	Feasible Branches	Infeasible Branches	All Branches (Tree WOT)	Lower Crown	Middle Crown	Upper Crown WOT
BF	0.130 (0.142)	0.123 (0.114)	0.124 (0.110)	0.025 (0.039)	0.117 (0.127)	0.266 (0.270)
WS	0.375 (0.343)	0.380 (0.378)	0.380 (0.367)	0.119 (0.096)	0.322 (0.320)	0.647 (0.634)

interest, errors caused by using the density based on the per branch method were examined. For balsam fir, sampling in the tree WOT, lower-crown, mid-crown, upper-crown WOT, and feasible branches yielded relative errors of 21.6, −3.8, 7.3, 9.0, and 5.7%, respectively. For white spruce, sampling in the same tree parts yielded relative errors of 13.8, −2.5, 3.9, 6.4, and −2.3%, respectively. Except for the tree WOT, the differences between the two methods were relatively small (< 10%). The average per tree differences between the two methods for the tree WOT was not significantly different from 0 for balsam fir (t, $P > 0.10$) and white spruce (t, $P > 0.05$). Thus, the errors caused by using the per branch method do not appear to be serious.

We examined the errors in terms of egg mass density caused by sampling different tree parts (tree WOT, mid-crown, and feasible branches) using the per branch and surface area methods for the averages shown in Tables 1 and 3, respectively, for balsam fir and white spruce. Each tree part was compared to TEMD. For balsam fir, the relative errors were larger for the per branch method compared to the surface area method with mixed results for white spruce. Results indicate, on the average, biases were larger for the per branch method. For sampling at mid-crown and feasible branches, the differences between the 2 methods did not appear to be serious given the small sample sizes and large variabilities present.

The average variances of egg mass density for the every branch dataset are shown in Table 4 for various tree parts. The average variances for white spruce were considerably larger than those for balsam fir for all tree parts, varying from about 2.4 times as large for feasible branches to about 5.5 times as large for the mid-crown. For balsam fir, sampling in the lower-crown, mid-crown, upper-crown WOT, and feasible branches yielded relative errors of −90.7, −44.9, 129.5, and −50.9%, respectively. For white spruce, sampling in the same tree parts yielded relative errors of −92.3, −41.4, 74.6, and −77.3%, respectively.

Tree (WOT) egg mass density variance per branch was underestimated when sampling the lower- and mid-crown by approximately 90 and 45%, respectively, for both balsam fir and white spruce. Tree egg mass density variance was considerably overestimated when sampling the upper-crown WOT with the relative error for balsam fir being about 1.7 times that for white spruce. Sampling feasible branches underestimated this variance with the relative error for white spruce being about 1.5 times that for balsam fir.

Table 5 shows $V(\bar{x})$, $MSE(\bar{x})$, precision %, and accuracy % for sampling in the tree WOT, mid-crown, and feasible branches for sample sizes of 2, 5, and 10 whole branches. Results show that sampling at mid-crown and feasible branches considerably underestimated $V(\bar{x})$ and $MSE(\bar{x})$ of the tree WOT with the same sample size for both species. $V(\bar{x})$ at mid-crown was 55.1 and 58.9% of $V(\bar{x})$ of the tree WOT with any sample size for balsam fir and white spruce, respectively, while $V(\bar{x})$ of feasible branches was 49.1 and 22.7% of $V(\bar{x})$ of the tree WOT with any sample size for balsam fir and white spruce, respectively. Similar results were obtained for $MSE(\bar{x})$ with $MSE(\bar{x})$ being

Table 4. Average variance of egg mass density (no. egg masses per 1000 cm^2, per branch method) for the 12 balsam fir (BF) and 10 white spruce (WS) trees in the every branch dataset.

Species	Feasible Branches	Infeasible Branches	All Branches[a]	Lower Crown	Middle Crown	Upper Crown WOT[b]
BF	0.0723	0.1573	0.1474	0.0137	0.0812	0.3383
WS	0.1729	0.8312	0.7615	0.0590	0.4482	1.3294

[a]Tree WOT
[b]Without Top

Table 5. V($\bar{x}$), MSE($\bar{x}$), precision %, and accuracy % for sampling various tree parts with n = 2, 5, and 10 using the per branch method for balsam fir (BF) and white spruce (WS), using the averages shown in tables 3 and 4.

		BF			WS		
		2	5	10	2	5	10
V($\bar{x}$)	Tree WOT[a]	0.0737	0.0295	0.0147	0.3808	0.1523	0.0762
	Mid-Crown	0.0406	0.0162	0.0081	0.2241	0.0896	0.0448
	Feasible Branches	0.0362	0.0145	0.0072	0.0864	0.0346	0.0173
MSE($\bar{x}$)	Tree WOT	0.0738	0.0296	0.0148	0.3823	0.1538	0.0777
	Mid-Crown	0.0406	0.0162	0.0081	0.2245	0.0900	0.0452
	Feasible Branches	0.0365	0.0148	0.0075	0.0876	0.0358	0.0185
Precision %	Tree WOT	242.4	153.4	108.3	181.0	114.4	81.0
	Mid-Crown	179.9	113.6	80.4	138.8	87.8	62.1
	Feasible Branches	169.9	107.5	75.8	86.2	54.5	38.6
Accuracy %	Tree WOT	242.6	153.7	108.8	181.3	115.0	81.8
	Mid-Crown	180.0	113.7	80.5	138.9	88.0	62.3
	Feasible Branches	170.6	108.7	77.4	86.8	55.5	39.8

[a]Without Top

slightly larger than V($\bar{x}$) with a given sample for a specific tree part. MSE($\bar{x}$) and V($\bar{x}$) decreased as sample size increased.

The precision % and accuracy % obtained by sampling at mid-crown and feasible branches were considerably smaller than that for the tree WOT for a given sample size. Both precision % and accuracy % decreased as sample size increased. The accuracy % was slightly larger than the precision % with a given sample size for a specific tree part. The difference increased slightly as sample size increased.

Results indicate that the combined effect, in terms of the bias associated with the sample mean $\bar{x}$, of sampling tree parts other than the tree WT and using the per branch method on MSE($\bar{x}$) was very small compared to the variance effect of sampling other tree parts. *The smallest precision % and accuracy % are obtained when sampling whole feasible branches.*

Sampling scheme dataset. The average per branch egg mass densities for the sampling scheme dataset are shown in Table 6. We examined both the effects of sampling the tree WOT, mid-crown, and whole feasible branches and the effects of sampling the first 40,

Table 6. Average egg mass density (no. egg masses per 1000 cm^2, per branch method) for the six balsam fir (BF) and five white spruce (WS) trees in the sampling scheme dataset. Standard deviations are in parentheses.

Species	Feasible Branches					Middle Crown	Tree WOT[a]
	Whole	70 cm	60 cm	50 cm	40 cm		
BF	0.142 (0.169)	0.219 (0.283)	0.216 (0.304)	0.236 (0.284)	0.210 (0.264)	0.124 (0.138)	0.117 (0.123)
WS	0.458 (0.353)	0.630 (0.492)	0.641 (0.509)	0.706 (0.541)	0.745 (0.585)	0.315 (0.236)	0.437 (0.377)

[a]Without Top

50, 60, and 70 cm of feasible branches from the branch tip. Once again there was considerable tree-to-tree and cluster-to-cluster variation.

Egg mass density calculated using the per branch method varied somewhat from that calculated using the surface area method (Tables 2 and 6) for various tree parts. Assuming density based on the surface area method to be the parameter of interest, errors caused by using the density based on the per branch method were examined. For balsam fir, sampling in the tree WOT, mid-crown, whole, 70, 60, 50, and 40-cm feasible branches yielded relative errors of 44.4, 18.1, 6.0, −5.6, −7.3, −7.5, and −12.5%, respectively. For white spruce, sampling in the same tree parts yielded relative errors of 11.2, −13.5, −1.1, −0.8, −5.9, −4.5, and −10.9%, respectively. Except for the tree WOT and mid-crown for balsam fir, the differences between the two methods were generally within 10%. The average per tree differences between the two methods for the tree WOT were not significantly different for balsam fir (t, $P > 0.20$) and white spruce (t, $P > 0.40$). Once again the errors caused by using the per branch method did not appear to be serious.

The errors in terms of egg mass density caused by sampling different tree parts using the per branch and surface area methods for the averages shown in Tables 2 and 6, respectively, for balsam fir and white spruce were examined. Each tree part was compared to TEMD. For balsam fir, the relative errors were larger with the per branch method for the tree WOT (36.0% compared to −5.8%), mid-crown (44.2% compared to 22.1%), and whole feasible branches (65.1% compared to 55.8%). The reverse was true for 70, 60, 50, and 40-cm feasible branches where the relative errors ranged from 151.2–174.4% for the per branch method and 169.8-196.5% for the surface area method.

For white spruce, the relative errors were larger with the per branch method for the tree WOT (7.6% compared to −3.2%) and mid-crown (−22.4% compared to −10.3%). The reverse was true for whole (12.8% compared to 14.0%) and 70, 60, 50, and 40-cm feasible branches where the relative errors ranged from 55.2–83.5% for the per branch method and 56.4–105.9% for the surface area method.

Results indicate that when sampling the tree WOT and mid-crown, biases were larger for the per branch method. However, when sampling whole 70, 60, 50, and 40-cm feasible branches, the biases were, in general, larger for the surface area method. Given the small sample sizes and large variabilities present, the differences between the two methods did not appear to be serious.

The average variances of egg mass density for the sampling scheme dataset are shown in Table 7. The average variances for white spruce were considerably larger than those for balsam fir for all tree parts, varying from about 2 times as large for the mid-crown to 5.7 times as large for 50 cm branches. For balsam fir, sampling in the mid-crown and whole, 70, 60, 50, and 40-cm feasible branches yielded relative errors of −47.3, −76.9, −9.6, −12.9, 19.5, and 79.4%, respectively. For white spruce, sampling in the same tree parts yielded relative errors of −72.2, −70.1, 4.7, −18.8, 76.9, and 106.7%, respectively.

Table 7. Average variance of egg mass density (no. egg masses per 1000 cm^2, per branch method) for the six balsam fir (BF) and five white spruce (WS) trees in the sampling scheme dataset.

Species	Feasible Branches					Middle Crown	Tree WOT[a]
	Whole	70 cm	60 cm	50 cm	40 cm		
BF	0.0462	0.1812	0.1746	0.2394	0.3596	0.1056	0.2004
WS	0.2305	0.8074	0.6266	1.3641	1.5937	0.2143	0.7712

[a]Without Top

Tree WOT egg mass density variance per branch was considerably underestimated when sampling at mid-crown with the relative error for white spruce being about 1.5 times that for balsam fir. Tree density variance was underestimated by 76.9 and 70.1% when sampling whole feasible branches for balsam fir and white spruce, respectively. For balsam fir, tree density variance was underestimated for 70 and 60-cm branches and overestimated for 50 and 40-cm branches. For white spruce, tree density variance was overestimated for 70, 50, and 40-cm branches and underestimated for 60-cm branches. The absolute relative error increased as branch size decreased for both species. The errors were larger for white spruce with 60, 50, and 40-cm branches.

Table 8 shows $V(\bar{x})$, $MSE(\bar{x})$ precision %, and accuracy % for sampling in the tree WOT, mid-crown, and whole 70, 60, 50, and 40-cm feasible branches for sample sizes of 2, 5, and 10 branches. Results show that sampling at mid-crown and whole feasible branches considerably underestimated $V(\bar{x})$ and $MSE(\bar{x})$ of the tree WOT with the same sample size for both species. $V(\bar{x})$ at mid-crown and for whole, 70, 60, 50, and 40-cm feasible branches was 52.7, 23.1, 90.4, 87.1, 119.5, and 179.4% of $V(\bar{x})$ of the tree WOT, respectively, regardless of sample size for balsam fir. $V(\bar{x})$ at mid-crown and for whole, 70, 60, 50, and 40-cm feasible branches was 27.8, 29.9, 104.7, 81.2, 176.9, and 206.0% of $V(\bar{x})$ of the tree WOT, respectively, regardless of sample size for white spruce. Similar results were obtained for $MSE(\bar{x})$ when sampling at mid-crown and whole feasible branches with $MSE(\bar{x})$ being somewhat larger than $V(\bar{x})$ for a given sample size and specific tree part. The difference between $MSE(\bar{x})$ and $V(\bar{x})$ increased as sample size increased. In all cases, $MSE(\bar{x})$ for 70, 60, 50, and 40-cm branches was larger than that for the tree WOT with the difference, in general, increasing as branch size decreased. For a given tree part, the difference increased relatively as sample size increased because the effect of the bias (relative error) caused by sampling the tree part on $MSE(\bar{x})$ became larger.

The precision % and accuracy % obtained by sampling at mid-crown and whole feasible branches were considerably smaller than that for the tree WOT for a given sample size. The precision and accuracy %'s were smallest for whole feasible branches. Both precision % and accuracy % for 70, 60, 50, and 40-cm branches were larger than that for the tree WOT with the difference increasing as branch size decreased. Both precision % and accuracy % decreased as sample size increased. The accuracy % was larger than the precision % with a given sample size for a specific tree part. The difference increased as sample size increased.

Results indicate that the combined effect, in terms of the bias associated with the sample mean $\bar{x}$, of sampling tree parts other than the tree WT and using the per branch method on $MSE(\bar{x})$ was relatively small to moderate when compared to the variance effect of sampling other tree parts for the mid-crown and whole feasible branches. On the other hand this combined effect was considerably larger for 70, 60, 50, and 40-cm feasible branches with the effect increasing as sample size increased. *The smallest precision % and accuracy %'s were obtained when sampling whole feasible branches.*

Table 8. V(x̄), MSE(x̄), precision %, and accuracy % for sampling various tree parts with n = 2, 5, and 10 using the per branch method for balsam fir (BF) and white spruce (WS), using the averages shown in tables 6 and 7.

		BF			WS		
		2	5	10	2	5	10
V(x̄)	Tree WOT[a]	0.1002	0.0401	0.0200	0.3856	0.1542	0.0771
	Mid-Crown	0.0528	0.0211	0.0106	0.1072	0.0429	0.0214
	Whole Branches	0.0231	0.0092	0.0046	0.1152	0.0461	0.0230
	70 cm Branches	0.0906	0.0362	0.0181	0.4037	0.1615	0.0807
	60 cm Branches	0.0873	0.0349	0.0175	0.3133	0.1253	0.0627
	50 cm Branches	0.1197	0.0479	0.0239	0.6820	0.2728	0.1364
	40 cm Branches	0.1798	0.0719	0.0360	0.7968	0.3187	0.1594
MSE(x̄)	Tree WOT	0.1012	0.0411	0.0210	0.3866	0.1552	0.0781
	Mid-Crown	0.0542	0.0225	0.0120	0.1155	0.0512	0.0297
	Whole Branches	0.0262	0.0123	0.0077	0.1179	0.0488	0.0257
	70 cm Branches	0.1083	0.0539	0.0358	0.4539	0.2117	0.1309
	60 cm Branches	0.1042	0.0518	0.0344	0.3685	0.1805	0.1179
	50 cm Branches	0.1422	0.0704	0.0464	0.7720	0.3628	0.2264
	40 cm Branches	0.1952	0.0873	0.0514	0.9117	0.4336	0.2743
Precision %	Tree WOT	368.1	232.8	164.4	152.9	96.7	68.4
	Mid-Crown	267.2	168.9	119.7	80.6	51.0	36.0
	Whole Branches	176.7	111.5	78.9	83.6	52.9	37.4
	70 cm Branches	350.0	221.2	156.4	156.5	99.0	70.0
	60 cm Branches	343.6	217.2	153.8	137.9	87.2	61.7
	50 cm Branches	402.3	254.5	179.8	203.4	128.6	91.0
	40 cm Branches	493.1	311.8	220.6	219.9	139.0	98.3
Accuracy %	Tree WOT	369.8	235.6	168.3	153.1	97.0	68.8
	Mid-Crown	270.8	174.6	127.6	83.7	55.7	42.4
	Whole Branches	188.3	129.1	102.3	84.6	54.4	39.5
	70 cm Branches	382.6	269.9	220.0	165.9	113.3	89.1
	60 cm Branches	375.3	264.6	215.7	149.5	104.7	84.6
	50 cm Branches	438.5	308.5	250.5	216.4	148.4	117.2
	40 cm Branches	513.7	343.5	263.6	235.2	162.2	129.0

[a]Without Top

Balsam Fir Versus White Spruce

Egg mass density on white spruce was considerably higher than that on balsam fir for all tree parts (Tables 1, 2, 3, and 6). The variance of egg mass density per branch for white spruce was also considerably higher than that for balsam fir for all tree parts (Tables 4 and 7).

For both species, egg mass density and the variance of egg mass density (1) increased from lower-to mid-to upper-crown and (2) increased, in general, as feasible branch size decreased. Also, egg mass density of whole feasible branches was higher than the density at mid-crown while variance of egg mass density of whole feasible branches was, in general, lower than that for all whole branches at mid-crown.

Average TEMD for the five clusters of trees varied from 0.034 to 0.273 ($\bar{x} = 0.127$) for balsam fir and from 0.122 to 0.869 ($\bar{x} = 0.341$) for white spruce. The cluster ratio of white spruce to balsam fir average TEMD varied from 1.44 to 4.18 ($\bar{x} = 2.91$). This ratio was significantly larger than 1.00 (t, $P < 0.025$). The cluster-to-cluster variability of egg mass density for white spruce trees ($s_1^2 = 0.0994$ was significantly larger (F, $P < 0.05$) than that for balsam fir trees ($s_2^2 = 0.0114$). Also, the tree-to-tree variation of egg mass density for the 10 white spruce trees ($s_1^2 = 0.0960$) was significantly larger (F, $P < 0.001$) than that for the 10 balsam fir trees ($s_2^2 = 0.0114$).

White spruce egg mass density, in general, increased as balsam fir egg mass density increased. The simple linear correlation between the two egg mass densities was moderately high ($r = 0.707$; t, $0.05 < P < 0.10$).

Estimation of TEMD

The results of this paper indicate that sampling at mid-crown and feasible whole branches yielded the most precise and accurate estimates of tree WT egg mass density compared to sampling tree WOT, the lower-crown, the upper crown WOT, and 70, 60, 50, and 40-cm whole feasible branches (Tables 5 and 8). Estimates based on sampling feasible branches were the most precise and accurate.

In order to determine where to sample in the tree to estimate TEMD, we investigated various sampling methods for sample sizes n = 2, 3, and 4 whole branches. The sample mean $\bar{x}$ is the mean of the n branches. The bias B for any sampling method is the difference between the average egg mass density per branch for that sampling method ($E(\bar{x})$) and TEMD (0.112 for balsam fir and 0.341 for white spruce). $E(\bar{x})$ is the average of all branches in the tree part or parts from which branches were selected for a given sampling method. B is caused by sampling tree parts other than tree WT and using the per branch method for determining egg mass density. Branch selection in a given tree part is assumed to be made using simple random sampling.

$V(\bar{x})$ and $MSE(\bar{x})$ are the variance and mean square error of $\bar{x}$ and are determined using the per branch variances ($V(X)$) in Table 4. When selecting branches from two or three crown classes, stratified random sampling is used with weights based on the proportion of tree foliage surface area in that class (i.e., 0.32, 0.50, and 0.18 for balsam fir and 0.30, 0.45, and 0.25 for white spruce for the lower-, mid-, and upper-crowns, respectively) (Simmons and Fowler 1982).

When n branches are selected from one tree part, $\bar{x} = \sum_{i=1}^{n} x_i/n$ and $V(\bar{x}) = V(X)/n$. When branches are selected from J tree parts, $\bar{x} = \sum_{j=1}^{J} w_j\bar{x}_j$ and $V(\bar{x}) = \sum_{j=1}^{J} w_j^2\, V(\bar{x}_j)$ where $\bar{x}_j = \sum_{i=1}^{n_j} x_i/n_j$ and n_j is the number of branches selected from the j^{th} tree part. The weight w_j is the ratio of the foliage surface area of the j^{th} part divided by the total foliage surface area of the J parts.

Bias distorts probability statements (Cochran 1977, Fowler and Witter 1982). The larger $|B| / \sqrt{V(\bar{x})}$, the larger the actual level of significance α will be compared to the nominal α (and the smaller the actual confidence coefficient will be compared to the nominal confidence coefficient). For $\alpha = 0.05$ and a normal distribution, the actual values of α are 0.0511, 0.0546, 0.0604, 0.0790, and 0.1700 for $|B| / \sqrt{V(\bar{x})} = 0.10, 0.20, 0.30, 0.50$, and 1.00, respectively. If the bias is no larger than 10% of $\sqrt{V(\bar{x})}$, the effect of bias on probability statements is negligible. Even with biases as large as 30% of $\sqrt{V(\bar{x})}$, the effect is quite modest.

Samples of 2, 3, and 4 whole branches. Table 9 shows $E(\bar{x})$, B, $V(\bar{x})$, $MSE(\bar{x})$, and $|B| / \sqrt{V(\bar{x})}$ for the averages from the every branch dataset using seven different methods with sample sizes of n = 2, 3, and 4 whole branches.

n = 2

The six methods are (only methods 1–3 and 5–7 are considered for n = 2):

1. select two branches from Tree WOT
2. select two branches from mid-crown
3. select two feasible branches
5. select one branch from each of the lower- and mid-crown
6. select one branch from each of the mid- and upper-crown
7. select one branch from each of the lower- and upper-crown.

The order of the methods in terms of decreasing accuracy and precision was 5, 3, 2, 7, 6, and 1 for balsam fir and 3, 5, 2, 7, 1, and 6 for white spruce. Selecting two feasible branches and selecting one branch from each of the lower- and mid-crowns yielded the most precise and accurate estimates, followed by selecting two branches from mid-crown. All other methods were considerably less accurate and precise.

Table 9. $E(\bar{x})$, B, $V(\bar{x})$, $MSE(\bar{x})$, and $|B| / \sqrt{V(\bar{x})}$ for the average of the 12 balsam fir and 10 white spruce trees using sampling methods 1–7 with n = 2, 3, and 4.

Sampling Method	$E(\bar{x})$	B	n=2			n=3			n=4		
			$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V(\bar{x})}$	$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V(\bar{x})}$	$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V(\bar{x})}$
Balsam fir											
1	0.124	0.012	0.0737	0.0738	0.044	0.0491	0.0492	0.054	0.0368	0.0369	0.063
2	0.117	0.005	0.0406	0.0406	0.025	0.0271	0.0271	0.030	0.0203	0.0203	0.035
3	0.130	0.018	0.0362	0.0365	0.095	0.0241	0.0244	0.116	0.0181	0.0184	0.134
4	0.114	0.002				0.0327	0.0327	0.011	0.0226	0.0226	0.013
5	0.081	−0.031	0.0322	0.0332	0.173	0.0215	0.0234	0.211	0.0161	0.0171	0.244
6	0.156	0.044	0.0678	0.0697	0.169	0.0458	0.0477	0.206	0.0339	0.0359	0.239
7	0.112	0.000	0.0494	0.0494	0.000	0.0275	0.0275	0.000	0.0247	0.0247	0.000
White spruce											
1	0.380	0.039	0.3808	0.3823	0.063	0.2538	0.2553	0.077	0.1904	0.1919	0.089
2	0.322	−0.019	0.2241	0.2245	0.040	0.1494	0.1498	0.049	0.1120	0.1124	0.057
3	0.375	0.034	0.0864	0.0876	0.116	0.0643	0.0655	0.134	0.0432	0.0444	0.164
4	0.342	0.001				0.1792	0.1792	0.006	0.1338	0.1338	0.003
5	0.241	−0.100	0.1708	0.1808	0.242	0.0901	0.1001	0.333	0.0854	0.0954	0.342
6	0.438	0.097	0.8634	0.8728	0.104	0.7708	0.7802	0.110	0.4317	0.4407	0.148
7	0.359	0.018	0.2923	0.2926	0.033	0.1549	0.1552	0.046	0.1462	0.1465	0.047

n = 3

The seven methods are
1. select three branches from Tree WOT
2. select three branches from mid-crown
3. select three feasible branches
4. select one branch from each of the three crowns
5. select one and two branches from the lower- and mid-crowns, respectively
6. select two and one branches from the mid- and upper-crowns, respectively
7. select one and two branches from the lower- and upper-crowns, respectively.

The order of the methods in terms of decreasing accuracy and precision was 5, 3, 2, 7, 4, 6, and 1 for balsam fir and 3, 5, 2, 7, 4, 1 and 6 for white spruce. Selecting three feasible branches and selecting one and two branches from the lower- and mid-crowns yielded the most precise and accurate estimates, followed by selecting three branches at mid-crown. All other methods were considerably less accurate and precise.

n = 4

The seven methods are
1. select four branches from Tree WOT
2. select four branches from mid-crown
3. select four feasible branches
4. select one, two, and one branches from the lower-, mid-, and upper-crowns, respectively
5. select two branches from each of the lower- and mid-crown
6. select two branches from each of the mid- and upper-crown
7. select two branches from each of the lower- and upper-crown.

The order of the methods in terms of decreasing accuracy and precision was 5, 3, 2, 4, 7, 6, and 1 for balsam fir and 3, 5, 2, 4, 7, 1, and 6 for white spruce. Selecting four feasible branches and selecting two branches from each of the lower- and mid-crowns yielded the most precise and accurate estimates, followed by selecting four branches at mid-crown. All other methods were considerably less accurate and precise.

Distortion of Probability Statements

Results clearly show that sampling feasible branches yielded the most accurate and precise estimates of TEMD for white spruce. Sampling branches from each of the lower- and mid-crowns (Method 5) yielded the most accurate and precise estimates of TEMD for balsam fir, but sampling feasible branches (Method 3) was almost as accurate and precise. Method 3 was more accurate for sample sizes larger than n = 12. The distortion of probability statements was considerably smaller for Method 3 than for Method 5 for both balsam fir and white spruce. For balsam fir, $|B| / \sqrt{V(\bar{x})} = 0.095, 0.116$, and 0.134 for n = 2, 3, and 4, respectively, using Method 3 and $|B| / \sqrt{V(\bar{x})} = 0.173, 0.211$, and 0.244 for n = 2, 3, and 4, respectively, using Method 5. For white spruce, $|B| / \sqrt{V(\bar{x})} =$ 0.116, 0.134 and 0.164 for n = 2, 3, and 4, respectively, using Method 3 and $|B| / \sqrt{V(\bar{x})}$ = 0.242, 0.333, and 0.342 for n = 2, 3, and 4, respectively, using Method 5. Actual α's varied from about 0.0511 to less than 0.0546 when the nominal $\alpha = 0.05$ for balsam fir, but with white spruce the acutal α's varied from somewhat less than 0.0546 to greater than 0.604. Distortion of probability increased with sample size. The distortions of both methods were only moderate.

COMMENTS

The following points should be considered in developing sampling plans to estimate egg mass densities in mixed spruce fir stands:
1. Considerable tree-to-tree and cluster-to-cluster variation;
2. The average egg mass density in spruce trees may be considerably higher than that in balsam fir trees; for the low density populations sampled in this study the ratio of

white spruce to balsam fir density varied from about 2 to 4.2 with an average of 2.91;

3. The branch-to-branch, tree-to-tree, and cluster-to-cluster variation of density may be considerably higher in white spruce compared to balsam fir trees; for the low density populations sampled in this study, the tree-to-tree variance for white spruce was approximately 9 times as large as that for balsam fir;
4. The biases due to using whole branches as the sampling unit with simple random sampling are relatively small;
5. The per branch mean and variance of egg mass density increases from lower- to mid- to upper-crowns;
6. The per branch variance of egg mass density at mid-crown is, in general, lower than that for the tree WOT;
7. The per branch variance of egg mass density for feasible branches increases as branch size decreases and is larger than the variance of tree WOT for smaller branch sizes;
8. The egg mass density of feasible branches is higher than that of tree WOT with the difference increasing as branch size decreases;
9. There may be a relatively strong positive linear correlation between white spruce and balsam fir egg mass density; for the five low-density clusters sampled in this study, the linear correlation coefficient was 0.71;
10. The most precise and accurate estimates of TEMD for white spruce are obtained from samples of whole feasible branches;
11. The most precise and accurate estimates of TEMD for balsam fir are obtained by selecting whole branches from each of the lower- and mid-crowns, but sampling whole feasible branches is almost as accurate and precise;
12. The distortion of probability statements caused by sampling whole feasible branches to estimate TEMD is relatively small—this distortion is moderate when sampling branches from each of the lower- and mid-crowns;
13. Sampling whole branches from the lower- and mid-crowns yields estimates of TEMD that are somewhat more precise and accurate than estimates based on sampling whole branches at mid-crown;
14. Sampling should not be done in the upper-crown;
15. The optimum sample unit is a whole feasible branch.

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