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Considerations When Sampling Spruce Budworm Egg Masses on Balsam Fir in the Lake States: Low to Extreme Population Levels

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

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ABSTRACT

Nineteen balsam fir trees, *Abies balsamea*, from five spruce-fir stands in Michigan's Upper Peninsula, were used to study egg mass densities and distributions. Ten were used to study the effects of branch size on egg mass density estimates. 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 and (or) the branch segment of interest. We determined the effects of the bias and the variance of the estimator, of sampling different parts of the tree, and of sampling different size branches. Points that should be considered when estimating spruce budworm egg mass densities on balsam fir were identified. Generally, sampling whole branches from the mid-crown gave the most precise and accurate estimates of tree egg mass density.

This is the third in a series of papers related to attempts to improve egg mass sampling of the spruce budworm, *Choristoneura fumiferana* (Clemens) (Lepidoptera: Tortricidae), (Fowler and Simmons 1982, Simmons and Fowler 1982). In this paper we (1) examine the effects of sampling balsam fir branches, *Abies balsamea* (L.) Miller, from different parts of the tree, (2) examine a range of egg mass densities and compare effects in terms of bias and the variance, and (3) look at the influence of branch size.

METHODS AND MATERIALS

The data used in this paper are from a study of spruce budworm egg mass sampling conducted in the Upper Peninsula of Michigan during the summers of 1979 and 1980 (Fowler and Simmons 1982, Simmons and Fowler 1982). In each of four stands of spruce-fir, four balsam fir trees were selected for complete enumeration of all observed egg masses on every branch of the tree. In one additional stand, three balsam fir trees were examined. These 19 trees were called "every branch trees."

We counted new egg masses and measured the foliage surface area for each branch. Egg mass density was calculated in two ways: (1) surface area method and (2) per branch method. For the surface area method, the total number of egg masses was divided by total surface area for the tree portion of interest. For the per branch method, the total number of new egg masses per unit of foliage was determined for each branch, then all branches in the tree portion of interest were averaged. For both methods the egg mass densities were expressed as egg masses per 1000 cm^2. The top, where branches were less than 70 cm, was treated separately as a single unit. Each branch examined was classified as being from 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 portion later classed as the "top."

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To compare all data with what can be practically obtained by a sampler using a pole-pruner, all branches in the mid-crown of enumerated trees were examined carefully from the ground before any branches were removed. Those branches judged to be feasible for a sampler to obtain with a pole-pruner were called "feasible branches."

In addition to the 19 "every branch trees," two balsam fir trees from each of the five stands were examined where only the branches deemed feasible to obtain with a pole-pruner were used. These 10 "sampling scheme trees" provided a means for comparing estimates of new egg mass densities on branches of different lengths.

The first "sampling scheme tree" selected in each stand was chosen because it contained a full crown. We felt that samplers tend to select these kinds of trees because they are easier to sample. The second tree selected was of average crown length and more representative of the kind of trees found in the stand. This provided us with a total of 10 "sampling scheme trees." For each we examined the feasible branches in the mid-crown and determined the number of egg masses and foliage surface area for the first 40, 50, 60, and 70 cm of that branch from the branch tip.

RESULTS AND DISCUSSION

In the results that follow, the information from the "every branch trees" will be referred to as the "every branch data set." The information from the "sampling scheme trees" will be referred to as the "sampling scheme data set." All means related to a given data set are arithmetic means.

Errors from Sampling a Portion of the Tree. To estimate egg mass density for an entire tree, we took the total number of new egg masses divided by the total surface area of the tree. The result is expressed as number of egg masses per 1000 cm^2 (TEMD). To examine the effects of sampling only a portion of the tree, we compared egg mass density of each portion of the tree (surface area method) to TEMD. Absolute error is the difference between the density of the tree portion and TEMD. Relative error is the absolute error divided by the tree density, multiplied by 100.

Every Branch Data Set. The average egg mass densities for the every branch data set are shown in Table 1. While there is considerable tree-to-tree and cluster-to-cluster variability, some trends are evident.

Over the range of stand egg mass densities (0.034 to 23.547 egg masses per 1000 cm^2), sampling from various parts of the tree yielded the following trends and relative errors: all branches from tree WOT (without top), 4.2%; lower crown, −55.6%; mid-crown, 19.4%; upper crown WT (with top), 44.5%; upper crown WOT (without top), 48.7%; and feasible branches, 18.6% (Table 2). These results suggest that (1) sampling the lower-crown consistently underestimates egg mass densities per tree with errors ranging from 50 to 70%; (2) sampling from the upper-crown, including or excluding the top, consistently overestimates egg mass density with errors ranging from 40 to 150%; (3) sampling from the mid-crown tends to overestimate egg mass density, although it also can underestimate

Table 1. Average egg mass density (no. egg masses per 1000 cm^2, surface area method) and standard deviations ( ) for the 19 balsam fir in the every branch data set.

Feasible Branches	Infeasible Branches	All Branches (Tree WOT)	Lower Crown	Middle Crown	Upper Crown WOT[b]	Upper Crown WT[c]	Tree WT (TEMD)
10.415 (11.344)	8.163 (9.498)	8.411 (9.498)	3.896 (4.613)	10.489 (13.187)	13.058[a] (15.879)	12.695[a] (15.380)	8.784 (9.657)

[a]Based on only 17 trees. The lower and middle crown values for 17 trees are 3.124 (2.953) and 8.648 (9.752), respectively.
[b]Without top
[c]With top

Table 2. Average egg mass density (no. egg masses per 1000 cm^2, surface area method), standard deviations and relative error for the 10 balsam fir trees in this sampling scheme dataset.

Characterization	Feasible Branches					Middle Crown	Tree	
	Whole	70 cm	60 cm	50 cm	40 cm		WOT[a]	WT[b]
Mean	10.831	10.988	10.568	10.702	10.583	10.868	8.545	9.140
Standard Deviation	10.183	9.443	9.549	10.067	10.481	11.909	9.344	10.378
% Error	18.5	20.2	15.6	17.1	15.8	18.9	6.5	
Error Range	−10 to 60%	−10 to 160%	−25 to 100%	−30 to 200%	−100 to 80%	0 to 40%	0 to 12%	

[a]Without top
[b]With top—TEMD

it, with errors ranging from −5 to 40%; (4) sampling only feasible branches from mid-crown tends to overestimate egg mass density, although underestimates can occur, with errors ranging from −5 to 30%.

Sampling Scheme Data Set. The average egg mass densities for the sampling scheme trees are shown in Table 2. With this table it is possible to examine the estimates from mid-crown and the influence of branch length on these estimates over a full range of egg mass densities. There is considerable tree-to-tree and cluster-to-cluster variation with some trends evident.

Generally, egg mass density estimation errors increased in magnitude as feasible branch size decreased. Therefore, if feasible branches are to be the sampling unit, whole branches should be used.

Errors from Using the Branch as a Sampling Unit. For these comparisons, we assumed TEMD as the parameter to be estimated. We used the per branch method for each portion of interest. However, because individual branches are neither the same size nor equal in surface areas, we expressed egg mass densities as egg masses per unit surface area. To obtain the egg mass density for the portion of the tree of interest we averaged the individual branches for that portion, then compared these estimates with TEMD.

Variances of egg mass densities were compared to the variance of the tree WOT (without top). Absolute errors for the variances were determined when compared to the tree WOT, and relative errors were the absolute errors divided by the tree WOT variance multiplied by 100.

The population variance ($V(\bar{x})$) and the mean square error ($MSE(\bar{x})$) of the sample mean were calculated for various tree portions. Precision and accuracy percents were calculated for 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

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

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

μ = tree WT egg mass density (TEMD)

For a more complete discussion of accuracy and precision of insect density estimates see Fowler and Witter (1982).

Every Branch Data Set. The average per branch egg mass densities for the every branch data set are shown in Table 3 for various parts of the tree. As with the surface area method there is considerable tree-to-tree and cluster-to-cluster variation.

Egg mass densities estimated by the per branch method varied somewhat with comparable estimates made using the surface area method (Tables 1 and 3). However, differences in relative errors caused by using the per branch method were no greater than 10%, with the exception of the tree WOT. Thus, the errors caused by using the per branch method did not appear to be serious. The key comparisons of special interest are the tree WOT, mid-crown and feasible branches. For all three, the per branch method had greater biases than the surface area method. Differences between the two methods for the mid-crown and feasible branches, however, did not appear large enough to be of serious concern.

The per branch method underestimated all tree WOT variances. The relative error for the mid-crown was comparatively small at −7% while the relative errors for the other three tree portions (lower-, upper-crown WOT, and feasible branches) were comparatively large, ranging from −40 to 90%.

The combined effects of the bias associated with sampling portions of the tree and of using the per branch method on MSE ($\bar{x}$) is illustrated in Table 4. Results show that sampling from the mid-crown overestimated V($\bar{x}$) and MSE ($\bar{x}$) of the tree WOT

Table 3. Average egg mass density (no. egg masses per 1000 cm^2, per branch method) and associated standard deviation, and average variance of egg mass density for the 19 balsam fir trees in the every branch dataset.

Statistic	Feasible Branches	Infeasible Branches	All Branches Tree WOT	Crown Lower	Crown Middle	Crown Upper-WOT
Mean	10.934	9.806	9.918	4.007	11.223	13.297[a]
Standard Deviation	12.359	12.580	12.588	5.581	15.241	16.394
Variance	45.283	182.422	173.075	23.895	160.742	104.392[a]

[a]Based on only 17 trees as there were no branches in the upper crown of two trees. The lower and middle crown values for 17 trees are 2.963 (standard deviation 2.878) and 8.872 (standard deviation 10.256), respectively, for means, and 8.496 and 54.748, respectively, for variances.

Table 4. V($\bar{x}$), MSE ($\bar{x}$), precision percentage, and accuracy percentage for sampling various tree parts with n = 2, 5, and 10 using the per branch method for balsam fir.

Parameter	Tree Portion	Sample Size (n) 2	5	10
V($\bar{x}$)	Tree WOT[a]	79.23	31.69	15.85
	mid-crown	116.14	46.46	23.23
	feasible branches	76.37	30.55	15.28
MSE ($\bar{x}$)	Tree WOT	80.52	32.98	17.13
	mid-crown	122.09	52.41	29.18
	feasible branches	81.00	35.17	19.90
Precision %	Tree WOT	101.3	64.1	45.3
	mid-crown	127.7	77.6	54.9
	feasible branches	99.5	62.9	44.5
Accuracy %	Tree WOT	102.1	65.4	47.1
	mid-crown	125.8	82.4	61.5
	feasible branches	102.5	67.5	50.8

[a]Without top

regardless of sample size. Sampling feasible branches only slightly overestimated V ($\bar{x}$) and MSE ($\bar{x}$) of the tree WOT regardless of sample size. For all, V ($\bar{x}$) and MSE ($\bar{x}$) decreased as sample size increased.

The precision % and accuracy % obtained by sampling at mid-crown were slightly larger than that from tree WOT for a given sample size. When sampling feasible branches, the precision and accuracy are nearly the same as those from tree WOT for a given sample size. For all, precision and accuracy decreased as sample size increased.

Overall, the results in Table 4 indicate that the combined effect of the bias associated with the sample mean of tree portions other than the tree WT and the bias caused by using the per branch method on MSE ($\bar{x}$) is very small compared to the variance effect of sampling other tree portions. The smallest precisions were obtained by sampling whole, feasible branches. The accuracies obtained from sampling whole, feasible branches were slightly larger than those obtained by sampling tree WOT.

Sampling Scheme Data Set. When we compared the two methods of calculating egg mass density, the per branch method always resulted in higher average values (Tables 2 and 5). Using TEMD as the parameter of interest, the absolute and relative errors for various portions of the tree were calculated. The WOT estimates were within 10%, while all other surface area estimates were within 15 to 20%. The per branch method overestimated for the remaining approaches, but relative errors were larger, ranging from 20 to 30%. Therefore, the per branch method probably provides adequate estimates with relative errors only somewhat larger than surface area method overestimates.

Tree WOT variance was considerably underestimated from mid-crown samples, but the relative error was nearly twice as great for whole, feasible branches. Tree WOT variance was overestimated from 40-cm branch samples, underestimated for 60 and 70-cm branch samples, and slightly overestimated for 50-cm branch samples. The results as shown in Table 6 suggest that from a practical viewpoint the influence of bias associated with the sample mean $\bar{x}$ from tree portions other than tree WT and using the per branch method on MSE ($\bar{x}$) is small to moderate. The smallest precision % and accuracy % are obtained when sampling whole, feasible branches.

Estimation of TEMD. The results of this paper indicate that sampling whole feasible branches yields the most precise estimates of tree WT egg mass density compared to sampling tree WOT, the lower-crown, the mid-crown, the upper-crown WOT, and 70, 60, 50, and 40-cm feasible branches (Tables 4 and 6). Estimates based on sampling whole, feasible branches and sampling tree WOT are approximately equal in accuracy and precision.

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 average egg mass density per branch for that sampling method (E($\bar{x}$)) and TEMD (7.876[4]

Table 5. Average egg mass density (no. egg masses per 1000 cm^2, per branch method) and associated standard deviation, for the 10 balsam fir trees in the sampling scheme data set. The average branch to branch variance is also indicated.

Statistic	Feasible Branches: Whole	70 cm	60 cm	50 cm	40 cm	Middle Crown	Tree WOT[a]
Mean	11.197	11.997	11.835	11.637	11.544	11.166	9.876
Standard Deviation	10.566	10.799	10.984	11.401	12.109	12.513	11.696
Variance	25.646	96.302	163.716	135.604	176.856	74.939	133.590

[a]Without top

[4]TEMD was recalculated for the 17 trees that had all the data required for this analysis.

Table 6. $V(\bar{x})$, $MSE(\bar{x})$, precision percentage, and accuracy percentage for sampling various tree parts with n = 2, 5, and 10 using the per branch method for balsam fir.

Parameter	Tree Portion	Sample Size (n) 2	5	10	Interpretation[b]
$V(\bar{x})$	Tree WOT[a]	68.40	27.35	13.63	S
	mid-crown	78.29	31.31	15.66	O
	whole branches	55.82	22.33	11.16	U
	70 cm branches	58.31	23.32	11.66	U
	60 cm branches	59.34	23.74	11.87	U
	50 cm branches	64.99	26.00	13.00	U
	40 cm branches	73.31	29.33	14.66	O
$MSE(\bar{x})$	Tree WOT[a]	68.94	27.90	14.22	S
	mid-crown	82.39	35.42	19.76	O
	whole branches	60.05	23.56	15.40	V
	70 cm branches	66.47	31.49	19.82	V
	60 cm branches	66.60	31.00	19.13	V
	50 cm branches	72.30	32.23	19.23	O
	40 cm branches	79.09	35.11	20.44	O
Precision %	Tree WOT[a]	90.5	57.2	40.5	S
	mid-crown	96.8	61.2	43.3	O
	whole branches	81.7	61.7	36.5	V
	70 cm branches	83.5	52.8	37.4	U
	60 cm branches	84.3	53.3	37.7	U
	50 cm branches	88.2	55.8	39.4	U
	40 cm branches	93.7	59.2	41.9	O
Accuracy %	Tree WOT[a]	90.8	57.8	41.3	S
	mid-crown	99.3	65.1	48.6	O
	whole branches	84.8	56.4	42.9	V
	70 cm branches	89.2	61.4	48.7	V
	60 cm branches	89.3	60.9	47.0	V
	50 cm branches	92.3	62.1	48.0	O
	40 cm branches	97.3	64.8	49.5	O

[a]Without top
[b]S = standard of comparison; O = over; U = under; and V = variable—some over, some under

for the 17 trees with branches in all three crowns [Table 1]). $E(\bar{x})$ 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 from a given tree part is made using simple random sampling.

$V(\bar{x})$ and $MSE(\bar{x})$ are the variance and mean square error of the sample mean ($\bar{x}$) and are determined using the per branch variances ($V(X)$) of the 17 trees (Table 3). 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 (Fowler and Simmons 1982).

When n branches are selected from one tree part:

$$\bar{x} = \sum_{i=1}^{n} x_i/n \text{ and } V(\bar{x}) = V(X)/n.$$

When branches are selected from J tree parts:

$$\bar{x} = \sum_{j=1}^{J} w_j \bar{x}_j \text{ and } V(\bar{x}) = \sum_{j=1}^{J} w_j^2 \; V(\bar{x}_j)$$

where: $\bar{x}_j = \sum_{i=1}^{n_j} x_i/n_j$

n_j = the number of branches selected from j^{th} tree part

w_j = the ratio of 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. Tables 7, 8, and 9 show $E(\bar{x})$, B, $V(\bar{x})$, MSE $(\bar{x})$, and $|B| / \sqrt{V}(\bar{x})$ for the average of the 17 balsam fir trees for the every branch dataset using seven different sampling methods with sample sizes of n = 2, 3, and 4 whole branches. With sample size n = 2 (Table 7) selecting two feasible branches yielded the most precise and accurate estimate, followed by selecting one branch from each of the lower- and upper-crown. All other methods were considerably less accurate and precise.

With sample size n = 3 (Table 8), selecting three feasible branches gave the most precise and accurate estimate, followed by selecting one and two branches from the lower- and upper-crowns, respectively. All other methods, except for method 5, were considerably less accurate and precise.

With sample size n = 4 (Table 9), selecting four feasible branches gave the most precise and accurate estimate, followed by selecting two branches from each of the lower-

Table 7. $E(\bar{x})$, B, $V(\bar{x})$, and $|B| / \sqrt{V}(\bar{x})$ for the average of the 17 balsam fir trees using sampling methods with n = 2.[a]

Sampling Method	$E(\bar{x})$	B	$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V}(\bar{x})$
1. 2 branches from tree WOT	8.245	0.369	46.25	46.39	0.054
2. 2 branches from mid-crown	8.872	0.996	27.37	28.37	0.190
3. 2 feasible branches	9.204	1.328	9.07	10.84	0.441
4. 1 branch from each of lower- and mid-crown	6.480	−1.396	21.14	23.14	0.303
5. 1 branch from each of mid- and upper-crown	9.945	2.069	37.56	41.84	0.338
6. 1 branch from each of lower- and upper-crown	6.270	−1.606	14.62	17.20	0.420

[a] $E(\bar{x})$ = expected value of x
B = bias
$V(\bar{x})$ = variance of the mean
$MSE(\bar{x})$ = mean square error of the mean
$|B| / \sqrt{V}(\bar{x})$ = absolute value of the bias relative to the standard error

Table 8. $E(\bar{x})$, B, $V(\bar{x})$, and $|B| / \sqrt{V(\bar{x})}$ for the average of the 17 balsam fir trees using sampling methods with n = 3.[a]

Sampling Method	$E(\bar{x})$	B	$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V(\bar{x})}$
1. 3 branches from tree WOT	8.245	0.369	30.84	30.97	0.066
2. 3 branches from mid-crown	8.872	0.996	18.25	19.24	0.233
3. 3 feasible branches	9.204	1.328	6.05	7.81	0.540
4. 1 branch from each of 3 crowns	7.571	−0.305	17.34	17.44	0.073
5. 1 and 2 branches from lower- and mid-crown	6.480	−1.396	11.50	13.44	0.412
6. 2 and 1 branches from mid- and upper-crown	9.945	2.069	21.85	26.13	0.443
7. 1 and 2 branches from lower- and upper-crown	6.270	−1.606	9.27	11.85	0.527

[a]$E(\bar{x})$ = expected value of x
B = bias
$V(\bar{x})$ = variance of the mean
$MSE(\bar{x})$ = mean square error of the mean
$|B| / \sqrt{V(\bar{x})}$ = absolute value of the bias relative to the standard error

Table 9. $E(\bar{x})$, B, $V(\bar{x})$, and $|B| / \sqrt{V(\bar{x})}$ for the average of the 17 balsam fir trees using sampling methods with n = 4.[a]

Sampling Method	$E(\bar{x})$	B	$V(\bar{x})$	$MSE(\bar{x})$	$\|B\| / \sqrt{V(\bar{x})}$
1. 4 branches from tree WOT	8.245	0.369	23.13	23.26	0.077
2. 4 branches from mid-crown	8.872	0.996	13.69	14.68	0.269
3. 4 feasible branches	9.204	1.328	4.54	6.30	0.623
4. 1, 2 and 1 branches from lower- mid-, and upper-crowns	7.571	−0.305	10.50	10.59	0.094
5. 2 branches from each of lower- and mid-crown	6.480	−1.396	10.60	12.55	0.429
6. 2 branches from each of mid- and upper crown	9.945	2.069	18.78	23.06	0.477
7. 2 branches from each of lower- and upper-crown	6.270	−1.606	7.37	9.89	0.594

[a]$E(\bar{x})$ = expected value of x
B = bias
$V(\bar{x})$ = variance of the mean
$MSE(\bar{x})$ = mean square error of the mean
$|B| / \sqrt{V(\bar{x})}$ = absolute value of the bias relative to the standard error

and upper-crown. All other methods except methods 4 and 5 were considerably less accurate and precise.

Distortion of Probability Statements. Sampling feasible branches gave the most accurate and precise estimate of TEMD. However, $|B| / \sqrt{V}(\bar{x})$ is largest for this sampling method, indicating the largest distortion of probability statements of all of the sampling methods. Actual α varied from about 0.07 to 0.09 when the nominal $\alpha = 0.05$. Distortion of probability statements increased with sample size. These distortions 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 exists.
2. The smallest precision and accuracy percentages are obtained when sampling whole, feasible branches.
3. Egg mass density estimation errors increase in magnitude as feasible branch size decreases.
4. When selecting two, three or four branches from a tree, the most precise and accurate method is to select branches from the mid-crown.
5. Even though sampling feasible branches from mid-crown yields the most precise and accurate estimates, distortion of probability statements is maximum.
6. Distortion of probability statements increases with sample size, but all distortions are only moderate.
7. The optimum sampling unit is a whole feasible branch from the mid-crown.

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