Implementing the Measurement Interval Midpoint Method for Change Estimation

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Abstract.—The adoption of nationally consistent estimation procedures for the Forest Inventory and Analysis (FIA) program mandates changes in the methods used to develop resource trend information. Particularly, it is prescribed that changes in tree status occur at the midpoint of the measurement interval to minimize potential bias. The individual-tree characteristics requiring midpoint values depend on the predictor variables needed to compute tree volume. Tree diameter change models are used to predict midpoint values for both future and past conditions. These updated diameters are used in conjunction with other information in a height model to obtain midpoint merchantable heights. These estimated diameter and height values are used to predict tree cubic-foot volume at the measurement interval midpoint. Limitations encountered in implementing this system included lack of information for some trees and inconsistencies between observed and updated values. A comparison is made between the previous method and the newly adopted technique, and effects on components of change are examined. Net change is unaffected by the new methodology.

Introduction

Since the passage of the 1998 Farm Bill that mandated an annualized approach to forest inventory in the United States, the Forest Service, U.S. Department of Agriculture's Forest Inventory and Analysis (FIA) program has been striving to develop more consistency among the regional FIA units. This move toward improved consistency resulted in the adoption of nationally consistent sampling design and estimation procedures (Bechtold and Patterson 2005). These new protocols include using stand- and tree-level attributes that reflect conditions at the midpoint of the sample plot measurement interval when estimating components of change (Scott *et al.* 2005). This approach assumes that, on average, events such as tree mortality, tree harvest, and conversions to and from forestland occur at the midpoint between inventory measurements. Under this assumption, the resulting estimates for components of change should be unbiased.

These new methods differ from those traditionally used in the northeast (NE-FIA) region, where only observed data recorded at the times the plots were measured were used to compute estimates of change components. This approach did not account for what tree volumes were at the time the change occurred, which caused bias in the estimates of change components. In this article, differences in estimates between the two methods are compared and obstacles encountered when implementing the new procedure are described along with potential solutions.

Data

The data used in this study are from NE-FIA sample plots in Maine. The 622 plots were initially measured under the annual inventory system (McRoberts 2005) in 1999 and were remeasured in 2004. These plots were partially or completely forested at either plot visit. Measurements at both times were taken on the 4-point cluster plot configuration (Bechtold and Scott 2005) in a spatially distributed sampling design (Reams *et al.* 2005). Each plot encompasses a land area of approximately 1/6 acre. Trees greater than or equal to 5.0 in diameter at breast height (d.b.h.) at either measurement were used for analysis.

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Methods

Traditional NE-FIA

Trees were assigned to growth components based on observed history. The volume of live trees less than 5.0 in d.b.h. at initial inventory (hereafter denoted T1) but equal to or larger than 5.0 in d.b.h. at remeasurement (hereafter referenced as T2) was described as ingrowth (I). Accretion (A) was determined for trees that were measured, alive, and at least 5.0 in d.b.h. at both measurements. Removal (R) volumes were from trees at least 5.0 in d.b.h. measured at T1 but harvested before T2. Volume loss due to mortality (M) was determined from trees at least 5.0 in d.b.h. that were alive at T1 and dead at T2. Removal (R) and mortality (M) volumes were based on tree characteristics at T1. Net change (N) was defined as N = I + A – R – M. Each plot contributes an observed volume in each of the five categories (N, I, A, R, M). These observed values were used to compute population-level estimates for each individual component and for the overall net change.

Individual-tree gross volumes were computed from d.b.h. and bole height using equations of Scott (1981). Gross volume was converted to net volume using observed percent cubic-foot cull (USDA Forest Service 2004).

Measurement Interval Midpoint

Under the newly prescribed midpoint approach, the assignment of trees to components relied on predicted d.b.h. at the midpoint. Ingrowth (I) is the volume of trees at the time they grow across the minimum d.b.h. threshold (5.0 in) between T1 and T2; however, only the volume at the ingrowth threshold (5.0 in d.b.h.) was assigned to the ingrowth component. Any additional growth beyond 5.0 in d.b.h. was attributed to the accretion (A) component. Volumes from trees that were measured, alive, and at least 5.0 in d.b.h. at both measurements were assigned to the accretion (A) component (no midpoint values were needed). Removal (R) volumes were from trees at least 5.0 in d.b.h. measured at T1 but harvested before T2. For these trees, growth from T1 to the midpoint was assigned to accretion (A) and the volume at the midpoint was attributed to R. Similarly, volume loss due to mortality (M) was determined from trees at least 5.0 in d.b.h. that were alive at T1 and dead at T2. Accretion was computed for the growth on these trees from T1 to the midpoint, and the midpoint volume was assigned to the M component. The definition of overall net change and computation of gross and net volumes for individual trees were identical for both methods.

Obtaining Midpoint Values

The above description of the midpoint method demonstrates that a mechanism for providing midpoint values was needed. For this study, three variables were necessary for computing midpoint volumes— d.b.h., bole height, and cubic-foot cull percent. An additional complication was that projections from observed measurements needed to be both from future (mortality and removal trees) and past (ingrowth) perspectives. The process used in this method is outlined as follows:

1. Predict the appropriate (future or past) relative change in diameter using the equations from Westfall (2006). The estimated relative change is used to compute the midpoint d.b.h.
2. Use this midpoint d.b.h. in the height model developed by Westfall and Laustsen (2006). For this study, coefficients developed for regionwide application were used (table 1). Assume the other model predictor variables did not change from the time they were observed to the interval midpoint. This model prediction will provide a midpoint bole height. Note that sometimes inconsistencies will occur between observed and modeled values (e.g., the midpoint height is smaller than the height at T1). To eliminate these problems, the harmonic proportioning method of Sheffield and Schweitzer (2005) was implemented. This technique uses observed and predicted values at the time the tree was measured to adjust the predicted values for the midpoint.
3. Use the midpoint d.b.h. and bole height to predict gross volume at midpoint. Finally, multiply the gross volume by 1 minus cubic-foot cull percent to obtain midpoint net volume. The cubic-foot cull percent was assumed to have not changed from the most recent measured value.

Table 1.—*Estimated coefficients for NE-FIA regionwide use in height model from Westfall and Laustsen (2006)[a].*

Group[b]	n	$\hat{a}_0$	$\hat{a}_1$	$\hat{a}_2$	$\hat{a}_3$	$\hat{a}_4$	$\hat{a}_5$	$\hat{a}_6$	$\hat{a}_7$
1	19807	−5.3174	101.7568	113.3938	94.1222	0.0701	0.0114	0.2937	2.6457
2	21700	−4.0879	80.9974	87.1315	72.7158	0.1037	0.0118	0.3178	2.7183
3	18719	−4.5683	79.6412	85.7464	72.4546	0.1124	0.0093	0.3557	2.5688
4	20628	−4.6716	88.5695	100.2259	82.4241	0.0797	0.0061	0.3832	2.2169
5	10850	−5.3714	97.5379	106.3982	93.0355	0.0792	0.0106	0.3753	2.7574
6	11321	−4.4011	72.6108	76.3698	69.0910	0.0856	0.0079	0.3098	2.7573
7	27235	−5.2346	92.1252	97.7856	88.4368	0.1071	0.0069	0.3267	1.0057
8	7016	−5.4536	117.1932	125.0373	109.9181	0.0934	0.0083	0.4022	1.0807
9	20527	−5.0346	96.7274	104.8101	90.9648	0.1046	0.0099	0.3591	1.1473
10	11694	−5.3508	101.5087	111.4904	94.1044	0.0866	0.0093	0.3584	1.2195
11	30489	−5.3292	89.8346	95.6066	86.4912	0.0897	0.0049	0.0780	0.1458
12	15448	−6.0106	104.1379	109.1728	98.2957	0.0746	0.0020	0.1413	0.1448
13	2494	−4.8963	108.0527	120.0344	105.3420	0.0900	0.0068	0.4163	1.1486
14	30243	−4.9946	91.5406	101.1159	86.9265	0.1023	0.0088	0.3699	0.9236
15	10833	−5.0550	97.5896	100.4159	92.9871	0.1025	0.0064	0.4685	1.0811
16	8134	−5.7404	105.8475	115.6039	96.1947	0.0972	0.0057	0.4044	1.1299
17	33815	−5.6585	100.6423	108.9352	93.9011	0.0917	0.0078	0.4060	1.1889
18	59269	−5.1022	89.5017	95.8707	86.3918	0.1076	0.0069	0.3463	1.0250

[a]
$$H = (\hat{a}_0 D + \hat{a}_1 CC_1 + \hat{a}_2 CC_2 + \hat{a}_3 CC_3)\ (1\ \ \exp(\ \ \hat{a}_4 DBH))^{(\hat{a}_5 CR + \hat{a}_6 TC + ((D/DBH) + 0.01)^{\hat{a}_7})}$$

[b] *Generally from Scott (1981). Contact an author of this paper for complete listing.*

Results and Discussion

The traditional and midpoint methods take different approaches to assigning volume to change components. Assuming the plots represent a simple random sample, estimates for each component were calculated for both methods (table 2). For ingrowth, the midpoint method produces a smaller estimate, because ingrowth volumes are always computed at the ingrowth threshold of 5.0 in d.b.h. The traditional method used the observed d.b.h. at the measurement subsequent to the crossing of the 5.0-in d.b.h. threshold, which would be a value of 5.0 or (often) higher. The accretion component under the midpoint method is notably larger when compared to the traditional approach. As noted above, the traditional method assigns all volume to ingrowth based upon the measurements at T2. The traditional method also did not account for any growth on mortality and removals—the volumes were based on observed data at T1. Thus, the difference arises from growth on ingrowth, mortality, and removals being added to the accretion component for the midpoint method. Volume of mortality and removals are also higher when using the midpoint approach. Because the midpoint values are used instead of the observed data at T1, the individual tree volumes are larger and the estimates for mortality and removals increase. When evaluating net change, the traditional and midpoint methods are identical.

Differences also occur in the precision of the estimates when comparing the traditional and midpoint methods. Table 3 shows that the standard error for ingrowth is nearly 10 percent less for

Table 2.—*Estimates of cubic-foot volume change by component on forest land in Maine for traditional NE-FIA and midpoint methods*

	Method		
Component	Traditional	Midpoint	Difference
Ingrowth	165,681,502	131,375,978	−34,305,524
Accretion	875,275,327	964,709,865	89,434,538
Mortality	357,180,873	370,311,502	13,130,629
Removals	606,569,440	648,567,825	41,998,385
Net	77,206,516	77,206,516	0

Table 3.—*Standard errors for estimates of cubic-foot volume change by component on forest land in Maine for traditional NE-FIA and midpoint methods.*

Component	Method		Percent of Traditional
	Traditional	Midpoint	
Ingrowth	12,738,701	11,514,120	90.4%
Accretion	34,781,244	34,302,255	98.6%
Mortality	21,999,892	22,715,502	103.3%
Removals	68,930,176	73,472,197	106.6%
Net	84,599,681	84,599,681	100.0%

the midpoint method. This difference is partially attributable to ingrowth volumes always being computed at the 5.0-in d.b.h. threshold under the midpoint approach, which results in less interplot variation. A related factor is that plots having ingrowth have a smaller value and the mean of the distribution is closer to zero. This factor is important because a number of plots have zero ingrowth and having these values closer to the mean reduces variance. The standard error for the accretion component is also smaller under the midpoint system. This difference is primarily due to the addition of accretion on ingrowth, mortality, and harvest trees. For instance, a plot that was entirely harvested would have zero accretion under the traditional method; however, this plot would have a nonzero accretion component using the midpoint method. This circumstance moves some plots closer to the mean of the distribution, which reduces the standard error.

The standard errors for mortality and removals components are larger when the midpoint method is used. This factor is a direct consequence of increased mortality and removal volumes that result from using the midpoint tree size instead of the tree size at T1. The means for mortality and removals increase under this scenario; however, a relatively large number of plots have zero mortality (174/622 = 28 percent) and/or zero removals (502/622 = 81 percent). The zero values for these plots are further from the mean under the midpoint method, which produces an increase in variance. The relationship between the amount of increase and number of zero-valued plots is evident by the larger increase for the removals component, which has substantially more zero-valued plots than mortality has. Because net change remains the same at the plot level, the net change standard errors for both methods are equal.

Several issues needed to be resolved when computing midpoint values for all trees. First, the values of many of the tree-level predictor variables in the d.b.h. and height models were assumed not to have changed since the last observation (i.e., crown class, crown ratio, tree class). This method is probably reasonable for short remeasurement intervals (~ 5 years); however, the validity of this approach may become more questionable as measurement intervals increase.

Another issue that arose was missing values for some predictor variables for certain trees and was most problematic for sapling trees (less than 5.0-in d.b.h.) that were alive at T1 but were either mortality or removal at T2. These trees needed midpoint values, but no data is collected for tree class (needed for height model) or cubic-foot cull (needed to estimate net volume). For this study, these attributes were examined for trees between 5.0 in and 6.0 in d.b.h. Nearly 75 percent of the trees in this diameter range were tree class code 2 (acceptable quality). Thus, for saplings missing tree class information, a 2 was assigned. Similarly, the mean cubic-foot cull percent was computed as approximately 6 percent; this value was assigned when the information was missing. Other possible solutions include (1) beginning to collect these data in the field, (2) respecifying the updating models so these variables are not needed, and (3) randomly selecting values from a distribution of valid values. In this study, nearly 6 percent of trees crossing the 5.0-in d.b.h. ingrowth threshold either died or were removed during the measurement interval. Factors affecting the proportion of trees in this category include length of measurement interval, site quality, stand age, and tree size/density relationships.

Last, an appropriate method for handling standing dead trees needed to be determined. Unlike trees that died and fell down during the measurement interval, standing dead trees are measured for d.b.h., bole height, and cubic-foot cull percent, so net volume can be computed and the use of midpoint values is not necessarily needed. Using observed data instead of modeled midpoint values, however, could create bias because it is unknown whether the tree still retains bark where the d.b.h. measurement is taken. Thus, trees that have a tendency to shed bark earlier would tend toward smaller volumes than trees of the same size that retain bark longer. To avoid this potential bias, all mortality volumes were based on projected midpoint attributes, regardless of whether the tree was measured at T2.

Conclusion

The midpoint method is more difficult to execute due to the need to produce midpoint values for all predictor variables in the volume equation. Acquiring mechanisms to produce these values may require significant resources and time (e.g., model development). In addition, a number of practical assumptions may be needed to implement the system across a wide range of tree history patterns. Overall, the level of difficulty encountered primarily depends on how many variables needed to be updated and what method(s) and information are needed to compute the updated values.

The justification for implementation of the midpoint method is reduced bias. Clearly, the traditional method overestimated ingrowth and underestimated the other components. It could also be asserted that the traditional method standard errors for the individual components were biased, because it was shown that the midpoint method standard errors were notably different. Estimates and standard errors for overall net change (I+A-M-R), which is often the element of interest, were identical for both methods. Compared to the traditional method, the midpoint method should provide more accurate estimates of components of change for forest resource conditions.

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