Avoiding Spurious Conclusions from Forest Service Estimates of Timber Volume, Growth, Removal, and Mortality

William Luppold, *Project Leader, Forest Service, Northeastern Research Station, 241 Mercer Springs Road, Princeton, WV 24740; and* **William H. McWilliams,** *Research Forester, Forest Service, Northeastern Research Station, 11 Campus Boulevard, Suite 200, Newtown Square, PA 19073.*

ABSTRACT: *Forest inventory statistics developed by the USDA Forest Service Forest Inventory and Analysis (FIA) units are useful in examining a variety of economic and biological issues, including forest-industry plant location, biological supplies of specific timber species, forest health, and long-term sustainability of timber resources. In general, these statistics accurately represent the resource, especially at the inventory-unit and state levels. However, several issues related to data collection must be understood to prevent spurious conclusions, especially when examining forest change characteristics such as removals, mortality, net growth, or the growth-removal ratio. Because FIA statistics are developed by sampling procedures, they are subject to sampling error. As the size of the forest area under study decreases, the number of observations used to develop FIA statistics decreases. The number of observations used to calculate FIA statistics can be particularly inadequate when examining net growth, removals, mortality, and growth-removal ratios of specific species for geographical areas smaller than inventory units. North. J. Appl. For. 21(4):194–199.*

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Forest inventory or forest survey statistics developed by the five USDA Forest Service Forest Inventory and Analysis (FIA) units are useful in examining a variety of economic and biological issues, including forest-industry plant location, biological supplies of specific timber species, forest health, and long-term sustainability of timber resources. With the development of the FIA Data Base Retrieval System (USDA Forest Service 2001b as explained by Hansen et al. 1992) and FIA Mapmaker (USDA Forest Service 2002), such data can be accessed easily at the county and subcounty levels. Additionally, the FIA Mapmaker allows one to view forest resources at the county level using a GIS approach. However, forest survey statistics are developed from a sampling process, and tradeoffs exist between the specificity of forest characteristics being examined and the size of the geographic area required to provide acceptable statistical properties.

Estimates of timber inventories are developed using a two-phase system. Phase one uses aerial photos to estimate the amount of forest land by county. During phase two, detailed field measurements are taken on randomly selected plots (USDA Forest Service 2001a). These measurements form the basis of equation-based estimates of the cubic-foot and board-foot volume of individual trees (Scott 1979, 1981). Reported estimates of forest inventory are developed by combining acreage information developed in phase one with plot information developed in phase two.

Two primary estimates developed by FIA units are growing stock and sawtimber volumes. Trees classified as growing stock are commercial species of good form that are at least 5 in. dbh. Trees are considered sawtimber size if they are softwoods at least 9 in. dbh or hardwoods at least 11 in. dbh. To qualify as sawtimber, a tree must contain at least one 12-ft sawlog or two noncontiguous 8-ft sawlogs. Growing stock volume is expressed in cubic feet, while sawtimber is expressed in board feet, International ¼-Inch Rule. Estimates of growing stock and sawtimber volumes are statistically reliable at the inventory-unit level because estimates are compiled from hundreds of sample plots and thousands of trees. However, as estimates are subdivided by species, the number of sample trees decreases substantially, thus increasing sampling errors (Kingsley and Powell 1981).

NOTE: William G. Luppold can be reached at (304) 431-2770; Fax: (304) 431-2772; wluppold@fs.fed.us.

A subset of the phase-two sample consists of remeasured locations that provide paired measurements that are inserted into previously developed equations to estimate average annual components of change: growth, removals, and mortality. In some cases, the number of remeasured plots and trees can be high; in other cases, the number of remeasured trees may be less than one-half of those measured to obtain volume estimates. Annualized indicators of change prior to the implementation of the new "annual" inventory measurement system were developed by dividing the phase-two estimates by the number of growing seasons between plot measurement.

The term net growth requires additional explanation to allay misunderstanding of its meaning. Net growth is the result of subtracting mortality from gross growth (ingrowth and accretion) and adjusting this estimate for reclassification of cull trees (cull decrement and cull increment). However, the sampling error reported for net growth only reflects the sampling error associated with gross growth. Net growth calculations also differ by regional FIA unit, thus introducing regional variations in interpreting timber sustainability. In the South, net growth is adjusted for the growth of trees that were harvested or died between inventory cycles. At the North Central FIA, the calculation of growth on removals and mortality is based on an estimate of growth at the mid-point of the remeasurement period. The Northeast FIA does not adjust growth of dead or removed trees because the lengthy period between survey cycles makes such adjustments difficult. Also, growth models specific to dying trees do not exist.

The best way to evaluate the quality of survey data is to examine the sampling errors associated with specific estimates. Sampling errors expressed as percents have been published at the survey unit level for growing stock and sawtimber volumes since the 1980s, but sampling errors have not been as available for estimates of growth, removals, and mortality. An alternative indicator of data quality is the number of sampled trees used to develop the estimate because sampling error will decline as the number of sampled trees increase. However, sample size is only roughly correlated to sampling error because the sample size needed to accurately measure a given population is a function of the size of the population, variations within the population, and sampling design (Shiver and Borders 1996).

In this article, we examine how statistical errors expand and the number of sample trees decline as we examine areas of differing sizes and sequentially examine estimates of annual growth, removals, and mortality. To accomplish this objective we compare resource statistics for six species (or species-groups) for a large state (Maine), a large survey unit (northeastern West Virginia), and a small survey unit (western Kentucky). The limitations of county-level data are demonstrated by examining the number of trees sampled in the two largest counties for the survey regions selected, Randolph County, WV and Trigg County, KY.

The data used in this study were developed from the custom table retrieval option of the FIA Data Base Retrieval System (USDA Forest Service 2001b, Hansen et al. 1992). Separate runs were made for each area studied, species or species-group, and category (growing stock and sawtimber: inventory, growth, removal, and mortality). Information on numbers of trees and plots is posted on the banner page of these runs. Sampling error data was developed by the Northeast Research Station FIA unit (T. Frieswyk, Northeastern Research Station, personal communication, Feb. 2003).

Data Issues at the State and Inventory-Unit Level

Maine is the most forested state in the United States with nearly 90% of its 19.7 million ac classified as forestland (Griffith and Alerich 1996). In 1995, over 2,800 sample plots containing over 144,000 trees were measured in this state (USDA Forest Service 2001b). Maine is unusual because of the high mortality of balsam fir and spruce species in the most recent complete inventory (Griffith and Alerich 1996).

The sampling errors associated with estimates of growing stock and sawtimber volumes were less than 10% for the six species examined and the number of sample trees used to estimate each volume exceeded 1,000 with the exception of aspen sawtimber (Table 1). The sampling errors associated with the growing stock and sawtimber growth were 15% or less for all species and the number of sample trees exceeded 500 for each estimate of growth. The sampling errors associated with removal statistics range from 7% for balsam fir growing stock to 17% for maple growing stock and sawtimber.

An unusual aspect of the 1995 Maine survey was that the number of trees used to estimate balsam fir mortality exceeded the number of trees used to estimate removals. With the exception of balsam fir, estimated sampling error increases as we sequentially examine growth, removal, and mortality (Table 1). Sampling errors for sawtimber mortality exceeded 20% for white pine, hard maple, hemlock, and aspen. A troubling aspect involving the large difference in sampling error for the different indicators of forest change is that the commonly used growth-removal-ratio utilizes three measurements (gross growth, removals, and mortality) with different sampling errors.

The northeastern inventory unit in West Virginia contained nearly 4.5 million ac of timberland and nearly 22 bbf of sawtimber in 1989 (DiGiovanni 1990). The volume of timber in this unit exceeds sawtimber volumes of most New England states with the exception of Maine and many central states including Indiana, Illinois, and Iowa (Powell et al. 1994). In 1989, nearly 1,000 sample plots and nearly 30,000 trees were measured in this unit.

As indicated in Table 2, the number of sample trees used to estimate growing stock and sawtimber volumes approached or exceeded 1,000 for the six most important species-groups in this unit. The sampling errors associated with this level of sampling were 10% or less for all estimates of growing stock and five of the six estimates of sawtimber. The number of trees used to estimate average growth in northeastern West Virginia exceeded 500 for growing stock and 350 for sawtimber with sampling errors

Table 1. Selective inventory statistics for Maine (1995) and the sampling errors and sample sizes associated with these statistics, by species-group.

Category	Balsam fir	White pine	Hard maple	Hemlock	Soft maple	Aspen
Volume of growing stock						
Vol. (million cf)	2,184	2,068	1,585	1,286	2,328	1,225
Sampling error (%)	(4)	(7)	(5)	(6)	(3)	(7)
No. of trees sampled	28,375	4,149	5,877	4,271	10,926	4,138
Volume of sawtimber						
Vol. (million bf)	2,960	8,161	4,434	3,878	3,538	2,291
Sampling error (%)	(6)	(7)	(6)	(7)	(6)	(9)
No. of trees sampled	6,137	2,108	1,209	1,712	1,288	737
Annual net growth of growing stock						
Vol. (million cf)	7.3	59.3	29.4	34.4	66.6	34.6
Sampling error (%)	(9)	(8)	(12)	(8)	(5)	(11)
No. of trees sampled	4,752	2,169	1,569	1,974	3,997	1,632
Annual net growth of sawtimber						
Vol. (million bf)	9.5	241.9	63.1	120.8	96.0	94.8
Sampling error (%)	(15)	(9)	(15)	(9)	(11)	(11)
No. of trees sampled	1,027	1,405	627	1,172	760	481
Annual removals of growing stock						
Vol. (million cf)	46.8	51.8	14.2	37.0	34.5	34.6
Sampling error (%)	(7)	(13)	(17)	(12)	(12)	(15)
No. of trees sampled	2,714	638	419	729	204	609
Annual removals of sawtimber						
Vol. (million bf)	143.9	211.8	44.8	110.9	57.3	59.9
Sampling error (%)	(8)	(13)	(17)	(12)	(12)	(15)
No. of trees sampled	820	514	106	497	107	194
Annual mortality of growing stock						
Vol. (million cf)	101.3	4.3	6.0	3.5	8.6	12.3
Sampling error (%)	(6)	(22)	(17)	(17)	(11)	(11)
No. of trees sampled	3,040	82	85	268	82	77
Annual mortality of sawtimber						
Vol. (million bf)	150.5	13.8	20.9	8.9	15.7	12.4
Sampling error (%)	(8)	(29)	(21)	(24)	(16)	(23)
No. of trees sampled	866	47	44	41	41	46

Table 2. Selective inventory statistics for northeastern West Virginia (1989) and the sampling errors and sample sizes associated with these statistics, by species-group.

Category	Yellow-poplar	Select red oak	Other white oak	Soft maple	Black cherry	Select white oak
Vol. of growing stock						
Vol. (million cf)	879	738	715	712	427	464
Sampling error (%)	(8)	(6)	(6)	(6)	(10)	(7)
No. of trees sampled	1,991	2,040	2,772	2,549	1,177	1,581
Vol. of sawtimber						
Vol. (million bf)	3,313	2,725	1,921	1,726	1,565	1,480
Sampling error (%)	(8)	(7)	(7)	(8)	(12)	(9)
No. of trees sampled	1,386	1,394	1,457	945	987	890
Annual net growth of growing stock						
Vol. (million cf)	25.1	21.4	16.3	25.1	12.7	10.6
Sampling error (%)	(12)	(11)	(11)	(19)	(15)	(12)
No. of trees sampled	807	949	1,160	1,133	529	683
Annual net growth of sawtimber						
Vol. (million bf)	125.1	106.0	60.2	81.8	66.9	45.4
Sampling error (%)	(13)	(11)	(11)	(16)	(16)	(14)
No. of trees sampled	608	690	673	453	368	421
Annual removals of growing stock						
Vol. (million cf)	4.9	5.2	4.2	6.8	5.7	4.1
Sampling error (%)	(31)	(24)	(32)	(45)	(30)	(31)
No. of trees sampled	75	94	91	110	58	64
Annual removals of sawtimber						
Vol. (million bf)	22.3	22.1	13.7	16.4	21.0	18.9
Sampling error (%)	(34)	(28)	(30)	(31)	(30)	(37)
No. of trees sampled	64	73	68	45	50	45
Annual mortality of growing stock						
Vol. (million cf)	1.8	1.3	1.7	1.6	0.6	0.5
Sampling error (%)	(38)	(22)	(21)	(64)	(42)	(25)
No. of trees sampled	45	62	94	48	22	28
Annual mortality of sawtimber						
Vol. (million bf)	3.5	3.3	3.0	3.8	0.3	0.5
Sampling error (%)	(46)	(30)	(29)	(72)	(72)	(50)
No. of trees sampled	18	29	30	13	8	8

ranging between 10 and 20%. The ambiguous relationship between sampling errors and sample size is highlighted by the fact that soft maple had the largest sample size and the largest sampling error. Still the correlation between sample size and sampling error associated with sawtimber growth is more consistent with the expected relationship between sampling error and the number of trees measured.

The number of sample trees used to estimate average removals of sawtimber by species group in northeastern West Virginia ranged from 58 to 110 for growing stock and 45 to 73% for sawtimber (Table 2). The associated sampling errors ranged from 24 to 45% with soft maple growing stock again being the most problematic estimate by having the highest number of sample points and the largest sampling error. Of all the statistics presented in Table 2, the estimates of sawtimber mortality again had the highest sampling errors (29 to 72%) and these estimates were based on the fewest number of observations (8 to 30 trees).

The western unit of Kentucky contained 771,000 ac of timberland and is one of the smaller survey units in the East. In 1988, 145 sample plots and more than 3,600 sample trees were measured in this unit (USDA Forest Service 2001b). The reduced number of trees measured resulted in sampling errors of volume measurements (growing stock and sawtimber) ranging from 12 to 26% depending on species. The reduction in sample size and the increase in sampling error are strongly evidenced in this unit as one moves from statistics concerning the most abundant species group, on other red oaks, to the sixth most abundant species group, select red oaks (Table 3).

The statistical validity of measurement of forest change varies considerably among species. The sampling errors for other red oak sawtimber growth, removals, and mortality are 24, 34, and 37%, respectively, but the comparable statistics for sweetgum are 61, 59, and 100%. Although there is no hard and fast rule of thumb that can be applied on the number of trees sampled and associated sampling errors using the information contained in Table 3, it appears that any estimate based on less than five observations has a very high sampling error.

Number of Trees Measured at the County Level

Randolph County is the second-largest county in West Virginia and contains 509,000 ac of timberland (USDA Forest Service 2001b). This county is in the center of the northeast survey region and contains 3.2 bbf. The size of this county rivals that of smaller survey units, as does the number of sample plots (123) and the number of trees sampled (4,094).

A comparison of Tables 2 and 4 indicates that forests may not be consistent across large survey units even when comparing a county in the center of a unit. In the case of northeast West Virginia, the eastern and western extremes

Table 3. Selective inventory statistics for western Kentucky (1988) and the sampling errors and sample sizes associated with these statistics, by species-group.

Category	Other red oak	Hickory	Select white oak	Other white oak	Sweet gum	Select red oak
Vol. of growing stock						
Vol. (million cf)	189	147	123	63	61	29
Sampling error (%)	(12)	(13)	(15)	(20)	(22)	(23)
No. of trees sampled	426	379	313	173	140	61
Vol. of sawtimber						
Vol. (million bf)	696	444	450	184	155	113
Sampling error (%)	(14)	(18)	(21)	(21)	(25)	(26)
No. of trees sampled	291	183	200	107	60	49
Annual net growth of growing stock						
Vol. (million cf)	3.0	1.5	3.3	0.7	0.4	0.3
Sampling error (%)	(21)	(31)	(25)	(55)	(38)	(35)
No. of trees sampled	107	94	130	50	30	18
Annual net growth of sawtimber						
Vol. (million bf)	12.6	6.7	16.5	3.4	2.0	4.0
Sampling error (%)	(24)	(25)	(28)	(40)	(61)	(59)
No. of trees sampled	72	46	86	29	11	18
Annual removals of growing stock						
Vol. (million cf)	4.7	1.6	2.5	0.8	1.1	1.2
Sampling error (%)	(35)	(32)	(30)	(37)	(59)	(37)
No. of trees sampled	58	19	31	12	14	14
Annual removals of sawtimber						
Vol. (million bf)	16.7	6.7	10.2	3.0	4.0	4.3
Sampling error (%)	(34)	(34)	(28)	(38)	(59)	(41)
No. of trees sampled	45	17	35	10	12	11
Annual mortality of growing stock						
Vol. (million cf)	0.9	0.8	0.6	0.4	0.1	0.5
Sampling error (%)	(26)	(45)	(42)	(58)	(100)[a]	(42)
No. of trees sampled	14	12	10	6	1	7
Annual mortality of sawtimber						
Vol. (million bf)	2.0	0.8	1.5	0.7	0.5	1.0
Sampling error (%)	(37)	(73)	(58)	(71)	(100)	(59)
No. of trees sampled	7	2	4	2	1	3

[a] Percentage error truncated at 100% for growth, removal, and mortality estimates.

Table 4. Number of sample trees used to estimate selective inventory statistics, Randolph County, WV 1989 forest inventory, by species-group.

Category	Black cherry	Soft maple	Select red oak	Beech	Yellow-poplar	Hard maple
Volume of growing stock	279	527	248	294	176	292
Volume of sawtimber	236	236	172	162	134	142
Annual net growth of growing stock	143	265	76	84	73	106
Annual net growth of sawtimber	130	110	56	53	59	46
Annual removals of growing stock	16	36	15	15	12	4
Annual removals of sawtimber	15	15	14	4	12	4
Annual mortality of growing stock	9	10	9	7	7	7
Annual mortality of sawtimber	5	2	4	5	2	2

have a much lower elevation than Randolph County. This variation in elevation is reflected in the presence of yellow-poplar in the unit as a whole versus the higher concentrations of black cherry and soft maple in Randolph County. However, the size of this county allows for a large number of observations to infer growing stock and sawtimber volumes with some degree of accuracy. Still, most removal estimates for specific species in this county are based on less than 15 observations, and all sawtimber mortality estimates are based on 5 observations or less. The lack of observations for estimating mortality and removals for even a large county makes any interpretation of species growth-removal-ratios at the county level difficult.

Trigg County, KY contains 159,000 ac of timberland (USDA Forest Service 2001b) and is at the southeastern edge of the Western Kentucky survey unit. In the 1988 survey, 33 plots and 144 trees were measured in this county. The declining number of observations found as we sequentially examine the most important to the sixth-most-important species, and growing stock volume to mortality is very evident in this county (Table 5). Although the number of survey trees may be sufficient to estimate growing stock and sawtimber volumes for some species in this county, interpreting detailed statistics on the components of forest change and growth-removal ratios for specific species should be avoided for this and similar counties.

The New Survey Regime

Currently, most eastern states have started or are planning to start collection of forest inventory data on a continuous annual basis with a full inventory being completed every 5 to 7 years. Although this effort should be welcomed by all who use inventory data, there are additional issues that should be considered when interpreting this data. First, while interim reports are already available after 2 or 3 years, one should wait for the full inventory cycle to be completed when examining individual species or statistics for a relatively small area. The new data collection effort is a different statistical design, and the number of remeasured plots that will occur under this design may be lower than previous survey efforts during the transition. This means that the statistics on inventory volume change must be carefully examined for the first full cycle of the new regime.

Another important change is that timber removal and mortality statistics will be based on a mid-point procedure similar to a process used by the North Central Research Station in past forest surveys. While the mid-point system may cause slower dispersal of these statistics, the added consistency of this approach is worth the wait. However, there is still some technical questions regarding the development of sampling errors for forest change statistics under the new survey procedure.

Summary and Conclusion

We examined the sampling errors associated with estimated growing stock volume, sawtimber volume, and annualized estimates of forest change at the state and inventory-unit level. In this effort, we also examined the number of observations used to estimate these statistics and observed the decreased number of trees measured as one sequentially examines growing stock volume, sawtimber volume, and annualized measures of growth, removals, and mortality. While sampling error size can only be roughly associated with the number of observations used to estimate inventory statistics, sampling errors increase as we examine species in lesser abundance or as we compare errors for growing stock volume to errors associated with mortality.

Table 5. Number of sample trees used to estimate selective inventory statistics, Trigg County, KY 1988 forest inventory, by species-group.

Category	Select white oak	Other red oak	Hickory	Other white oak	Yellow-poplar	Yellow pines
Volume of growing stock	134	111	91	73	30	16
Volume of sawtimber	89	82	38	47	18	14
Annual net growth of growing stock	59	39	29	19	11	16
Annual net growth of sawtimber	34	30	11	11	8	14
Annual removals of growing stock	11	9	4	3	2	0
Annual removals of sawtimber	9	4	4	3	1	0
Annual mortality of growing stock	5	5	5	4	0	0
Annual mortality of sawtimber	1	2	0	1	0	0

Of the indicators examined, estimates of removal and mortality are the most problematic. Even at the state level, there may be insufficient observations to estimate sawtimber mortality of a specific species. The low numbers of sampled trees used to estimate removals and mortality at the subinventory unit level means that the often used growth-removal-ratio could provide spurious information when examining a small geographic area. Still, there are ways to minimize potential for such conclusions from detailed examination of inventory data. If the number of sample trees is insufficient for accurate estimates, it may be necessary to expand the examination area. This would require combining inventory units with similar forest attributes across state lines.

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