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Comparison of Past, Present, and Future Volume Estimation Methods for Tennessee

Stanley J. Zarnoch, Alexander Clark III, and Ray A. Souter

Abstract

Forest Inventory and Analysis 1999 survey data for Tennessee were used to compare stem-volume estimates obtained using a previous method, the current method, and newly developed taper models that will be used in the future. Compared to the current method, individual tree volumes were consistently underestimated with the previous method, especially for the hardwoods. The taper models produced estimates very similar to the current method for both hardwoods and softwoods. When expanded to a statewide basis, the previous method differed from the current by -2.128 by 10^9 cubic feet, which represents an 8.16-percent underestimate. Hardwoods again were more severely underestimated than softwoods. Conversely, results from the taper method deviated only 0.230 by 10^9 cubic feet from the current method, or 0.88 percent, which is of little concern.

Keywords: FIA, taper equations, volume

Introduction

The Forest Inventory and Analysis (FIA) Program in the Southern Research Station (SRS) has conducted volume surveys across the Southern States for the past several decades. During this time, there have been many changes in technology and survey methodologies that have resulted in alterations of the survey protocol. In addition, the original Southeastern and Southern Forest Experiment Stations, which were responsible for the eastern and western halves, respectively, of the surveys of the Southern States, have been merged into the current Southern Research Station. This also has resulted in various changes to ensure uniformity of methods throughout the South. Hence, comparing surveys over time for any one State is difficult because any changes observed might be due to changes in the forest resource or merely changes in the methodology used in the survey or a combination of both. The objectives of this paper are to (1) summarize the evolution of individual tree volume methodologies used by the Southern Research Station, and (2) compare the volume estimates on an individual tree and total State basis derived from past, present, and future methods for the 1999 Tennessee survey.

Stanley J. Zarnoch is Mathematical Statistician, USDA Forest Service, Southern Research Station, Asheville, NC 28802-2680; Alexander Clark is Wood Scientist in the Disturbance and Management of Southern Forest Ecosystems, USDA Forest Service, Southern Research Station, Forest Sciences Laboratory, Athens, GA 30602-2044; and Ray A. Souter is Forest Biometrician, Forestech International, LLC, Athens, GA 30604-6412.

Volume Estimation

The 1999 Tennessee survey (Schweitzer 2000) was analyzed using the SRS volume methodology, which is based on the typical D^2H volume equations (Spurr 1952) produced on a species or species group basis using a simple linear regression model. Gross cubic foot volume inside bark from a 1-foot stump to a 4-inch upper diameter outside bark (d.o.b.) was predicted for each sample tree based on diameter at breast height (d.b.h.) and total height (H) and did not include forks or limbs outside of the main bole. This method is identical to the original volume methodology used by the Southeastern Forest Experiment Station (SE), except that the SE method included forks and limbs in the volume estimates. Because the SE method was never used in Tennessee, it will not be discussed further in this paper.

The previous Tennessee survey in 1989 was the responsibility of the Southern Forest Experiment Station (SO) and was based on obtaining numerous d.o.b. measurements on each sample tree and computing volume by accumulating Smalian bolt-volume estimates. Hence, the

typical regression volume equations that were used with the SRS methodology in 1999 never were developed for the 1989 survey. The SO method computed volume inside bark based on a 1-foot stump height to an arbitrary cruiser-selected upper stem d.o.b., which usually was around 4 inches but often was quite larger, depending on the size and condition of the tree and merchantable top limit as estimated at the time of the inventory. Merchantable top limits have changed since then and are now to a fixed 4-inch d.o.b. top. Thus, compared to the 1999 survey, the 1989 volume should be considerably less.

Recently, advances in analytical techniques have led to the development of a new system of volume equations based on tree taper models (Souter and others, in press). A system of nonlinear equations was fitted to stem diameter inside bark (d.i.b.) measurements to produce a taper curve that is integrated between any two heights to obtain the volume of wood between those two points. The advantage is the potential to have a somewhat better fit than the typical regression volume equations. More importantly, however, volume can be obtained for any set of merchantability standards simply by changing the points of integration on the tree bole model; no new models need to be refitted. The default is volume inside bark from a 1-foot stump height to a height where upper stem d.o.b. is 4 inches. The taper model is similar to the SRS method in that it is based on the main tree bole and does not include volume in forks or limbs. Table 1 gives a summary of the four volume methods used throughout the South.

Methods

The 1999 Tennessee survey was used to compare three volume estimation methods: the Southern Forest Experiment Station (SO) method, the Southern Research Station (SRS) method, and the taper (TAPER) model. Limitations of funds and time prohibited resurveying Tennessee to produce the SO estimate based on Smalian tree bolts; however, an approximation was used to mimic the methodology. In essence, the 1989 Tennessee data were used as a basis for the SO method to which D^2H regression equations were fitted for seven species groups (table 2). These equations were used on the 1999 Tennessee survey to calculate volume on an individual-tree basis and then expanded to a total State basis by applying the appropriate plot and county expansion factors. The SRS and TAPER method results were computed simply by applying their equations to the 1999 Tennessee survey data.

Evaluation of the three methods was on an individual-tree and total State volume basis. Volume differences and percentage differences were calculated for hardwoods and softwoods for each of the poletimber and sawtimber categories.

Results and Discussion

The 1999 Tennessee survey (Schweitzer 2000) was based on the SRS method, which was used as the standard for

Table 1—Summary of volume methods used in the past, present, and future

Method	Stump height	Upper d.o.b.	Main bole	Limbs and forks	Analytical method
	feet	*inches*			
Southern Forest Experiment Station	1	Field cruiser-selected	Yes	No	Cumulative Smalian bolts
Southeastern Forest Experiment Station	1	4	Yes	Yes	Linear regression
Southern Research Station	1	4	Yes	No	Linear regression
Taper Model	Variable (1-foot default)	Variable (4-inch default)	Yes	No	System of nonlinear equations

d.o.b. = diameter outside bark.

Table 2—Gross cubic volume equations[a] developed from the 1989 data for the Southern Forest Experiment Station method

Volume equation[b c]	Timber type	Mean 1989 stopper d.o.b.	Trees	$\hat{\beta}_0$	$\hat{\beta}_1$	R^2	Mean square error
		inches	*no.*				
2	Pole	4.1	895	-0.71267	0.00206	0.87	1.07
	Saw	4.6	1,057	1.69682	0.00180	0.87	17.92
3	Pole	4.6	9	-0.75168	0.00218	0.90	4.13
	Saw	7.3	55	3.16103	0.00158	0.80	574.82
4	Pole	4.3	1,272	-0.32465	0.00210	0.87	0.96
	Saw	4.9	1,700	2.69948	0.00168	0.94	32.27
5	Pole	4.6	4,725	-0.25893	0.00174	0.87	2.28
	Saw	6.8	8,295	8.09304	0.00122	0.81	114.14
6	Pole	4.4	1,589	-0.47320	0.00176	0.88	2.45
	Saw	5.8	2,606	7.78129	0.00133	0.86	124.15
7	Pole	4.7	5,503	-0.31562	0.00173	0.87	2.21
	Saw	6.9	5,312	6.62802	0.00132	0.87	190.83
8	Pole	4.7	695	-0.33101	0.00173	0.83	1.09
	Saw	7.0	91	5.01258	0.00111	0.62	25.04

[a] Gross cubic volume (cubic feet) = $\hat{\beta}_0 + \hat{\beta}_1 D^2 H$, where D is d.b.h. (inches) and H is total tree height (feet).

[b] Volume equation 1 is for longleaf pine and because there was no longleaf pine in Tennessee, a volume equation was not developed for this species.

[c] Species composition for the volume equations that were developed from the 1989 data. Boldfaced species were not present in the 1989 data that were used to fit the volume equations but were in the 1999 data for which a volume equation was required for the subsequent analysis. Volume equation 2 = *Pinus* (*echinata*, *taeda*); volume equation 3 = *Taxodium* (*distichum*), *Nyssa* (*aquatica*); volume equation 4 = *Juniperus* (*virginiana*), *Pinus* (*pungens*, *rigida*, *stobus*, *virginiana*), *Tsuga* (*canadensis*, ***caroliniana***); volume equation 5 = *Quercus* (*alba*, *bicolor*, *coccinea*, *falcata*, *imbricaria*, ***laevis***, *lyrata*, *macrocarpa*, *michauxii*, *muehlenbergii*, *nigra*, *nuttallii*, *palustris*, *phellos*, *prinus*, *rubra*, *shumardii*, *stellata*, *velutina*); volume equation 6 = *Liquidambar* (*styraciflua*), *Liriodendron* (*tulipifera*), *Nyssa* (*sylvatica*); volume equation 7 = *Acer* (*barbatum*, *negundo*, *nigrum*, ***pennsylvanicum***, *rubrum*, *saccharinum*, *saccharum*), *Aesculus* (*glabra*, *octandra*), *Betula* (*alleghaniensis*, *lenta*, *nigra*), *Carya* (sp., *aquatica*, ***cordiformis***, ***glabra***, *illinoensis*, ***laciniosa***, ***ovata***, ***texana***, ***tomentosa***, ***pallida***), ***Castanea*** (***dentata***), *Catalpa* (sp.), *Celtis* (*laevigata*, *occidentalis*), *Cornus* (*florida*), *Diospyros* (*virginiana*), *Fagus* (*grandifolia*), *Fraxinus* (*americana*, *pennsylvanica*, *quadrangulata*), *Gleditsia* (*aquatica*, *triacanthos*), *Gymnocladus* (*dioicus*), *Ilex* (*opaca*), *Halesia* (*carolina*), *Juglans* (*cinerea*, *nigra*), *Maclura* (*pomifera*), *Magnolia* (*acuminata*, *grandiflora*, *virginiana*, ***fraseri***), *Morus* (*rubra*), ***Persea*** (***borbonia***), ***Planera*** (***aquatica***), *Platanus* (*occidentalis*), *Populus* (sp., ***deltoides***), *Prunus* (*serotina*), *Robinia* (*pseudoacacia*), *Salix* (sp.), *Sassafras* (*albidum*), *Tilia* (*americana*, *heterophylla*, ***caroliniana***), *Ulmus* (*alata*, *americana*, ***crassifolia***, *rubra*, *serotina*, *thomasii*); *volume equation 8 =* *Ailanthus* (*altissima*), ***Amelanchier*** (**sp**., ***arborea***), *Alnus* (*glutinosa*), ***Bumelia*** (**sp**.), *Carpinus* (*caroliniana*), *Cercis* (*canadensis*), *Crataegus* (sp.), ***Halesia*** (sp.), *Magnolia* (*macrophylla*), *Malus/Pyrus* (sp.), *Morus* (*alba*), *Ostrya* (*virginiana*), *Oxydendrum* (*arboreum*), *Paulownia* (*tomentosa*), ***Prunus*** (**sp**. *except* ***serotina***), *Quercus* (*marilandica*), *Citrus* (sp.), miscellaneous species.

comparison purposes in this study. Generally, the SO method consistently underestimated individual tree volume, as expected, because it usually does not go to the upper 4-inch d.o.b. Hardwoods are more affected than softwoods (table 3); absolute cubic foot differences for hardwoods were nearly three times that of softwoods, and percentage differences were a little less than twice. For both hardwoods and softwoods, absolute differences for sawtimber were seven times that of poletimber, but on a percentage basis poletimber was about three times that of sawtimber.

Little difference was observed between the TAPER and SRS methods; hardwoods and softwoods responded somewhat similarly (table 3). Poletimber exhibited a very small absolute underestimate, and sawtimber had a larger overestimate; however, both were within three-fourths of a cubic foot of the SRS method. The trends were the

Table 3—Average individual tree volumes based on the SRS, SO, and Taper volume equation methods for the 1999 data

					SO versus SRS			Taper versus SRS		
Wood species	Timber type	Mean 1989 stopper d.o.b.	Sample trees	SRS volume per tree	SO volume per tree	Diff. from SRS	Diff. from SRS[a]	Taper volume per tree	Diff. from SRS	Diff. from SRS[a]
		inches	*number*	*- - - - - - - cubic feet - - - - - - -*			*%*	*- - - cubic feet - - -*		*%*
Hard	Pole	4.6	32,322	5.75	5.33	-0.42	-7.00	5.74	-0.01	-1.68
Hard	Saw	6.7	12,247	35.61	32.32	-3.29	-2.15	35.97	0.36	1.94
Soft	Pole	4.2	6,720	4.18	3.99	-0.20	-4.21	4.17	-0.01	-0.17
Soft	Saw	4.9	3,647	22.57	21.34	-1.23	-1.69	23.23	0.66	2.18

SRS = Southern Research Station; SO = Southern Forest Experiment Station; d.o.b. = diameter outside bark.

[a] The average Diff. from SRS (percent) is calculated as the average of the percentage difference from the SRS method on an individual tree basis. This is not equivalent to the ratio of Diff. from SRS divided by SRS volume per tree converted to a percentage, which can be calculated simply from the entries in the table and is approximately equivalent to the Diff. from SRS (percent) calculated on the total State basis using the appropriate plot and county expansion factors (refer to table 4).

same on a percentage basis and were within about 2 percent of the SRS method, which had substantially less variation than with the SO method.

Further comparisons of the three methods on an individual tree basis are shown in figure 1, where volume versus d.b.h. is illustrated. The SRS and TAPER methods produce virtually identical results for hardwoods; the SO results deviate substantially at larger d.b.h. This underestimation by the SO method is most probably due to the tendency of selecting upper d.o.b.'s at a lower height on large d.b.h. trees, resulting in less volume. All three methods are similar for softwoods; the SRS and TAPER results are nearly the same for d.b.h.'s less than 20 inches.

An evaluation expanded over the whole State is important because it takes into account the distribution of trees among the various tree species and size classes, giving a representative picture of the differences in estimates by the three methods. Overall, the SO method results differed from the SRS by -2.128 by 10^9 cubic feet, which represents an 8.16-percent underestimate (table 4). Hardwoods again were more severely underestimated on an absolute and percentage basis than softwoods. Conversely, the TAPER method results deviated only 0.230 by 10^9 cubic feet, from the SRS, or 0.88 percent, which is of little concern.

Figure 2 illustrates the distribution of total volume versus d.b.h. class for the three methods. Again, the TAPER and

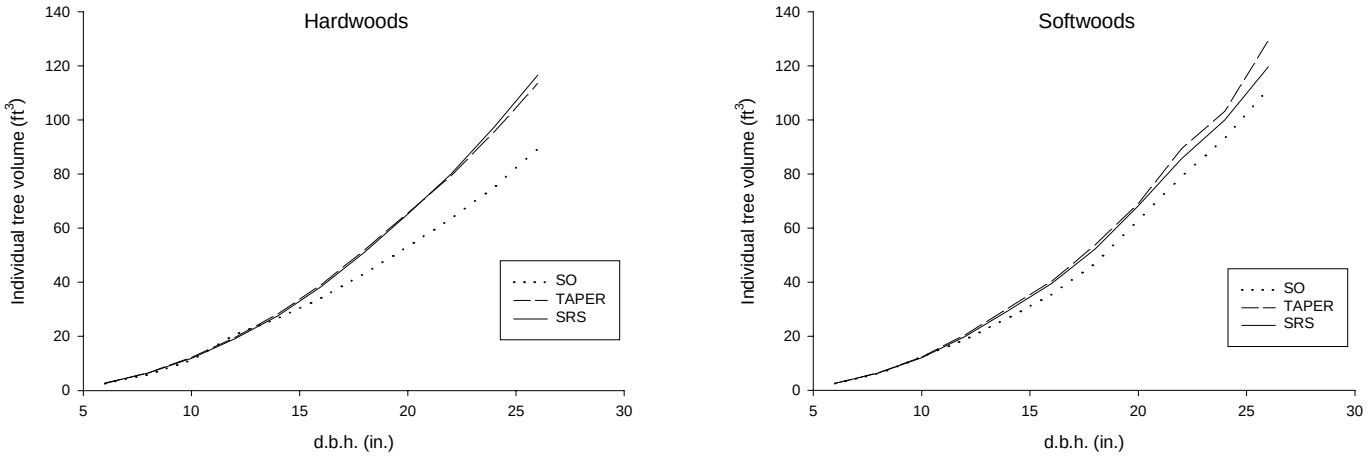

Figure 1—Individual tree volume for the 1999 Tennessee survey.

Table 4—Total State volume based on the SRS, SO, and Taper volume equation methods for the 1999 data

Wood species	Timber type	Mean 1989 stopper d.o.b.	Trees	SRS total volume	SO versus SRS: SO total volume	SO versus SRS: Diff. from SRS	SO versus SRS: Diff. from SRS[a]	Taper versus SRS: Taper total volume	Taper versus SRS: Diff. from SRS	Taper versus SRS: Diff. from SRS[a]
		inches	*no.*	*- - - - - - 10^9 cubic feet - - - - - - -*			*%*	*- - 10^9 cubic feet - -*		*%*
Hard	Pole	4.6	32,322	6.643	6.154	-0.489	-7.36	6.630	-0.013	-0.20
Hard	Saw	6.7	12,247	15.611	14.176	-1.435	-9.19	15.768	0.156	1.00
Soft	Pole	4.2	6,720	0.983	0.936	-0.047	-4.81	0.981	-0.002	-0.20
Soft	Saw	4.9	3,647	2.844	2.687	-0.157	-5.50	2.933	0.090	3.16
Total		5.6	54,936	26.081	23.953	-2.128	-8.16	26.312	0.230	0.88

SRS = Southern Research Station; SO = Southern Forest Experiment Station; d.o.b. = diameter outside bark.

[a] The average Diff. from SRS (percent) is calculated as the average of the percentage difference from the SRS method on an individual tree basis. This is not equivalent to the ratio of Diff. from SRS divided by SRS volume per tree converted to a percentage, which can be calculated simply from the entries in the table and is approximately equivalent to the Diff. from SRS (percent) calculated on the total State basis using the appropriate plot and county expansion factors.

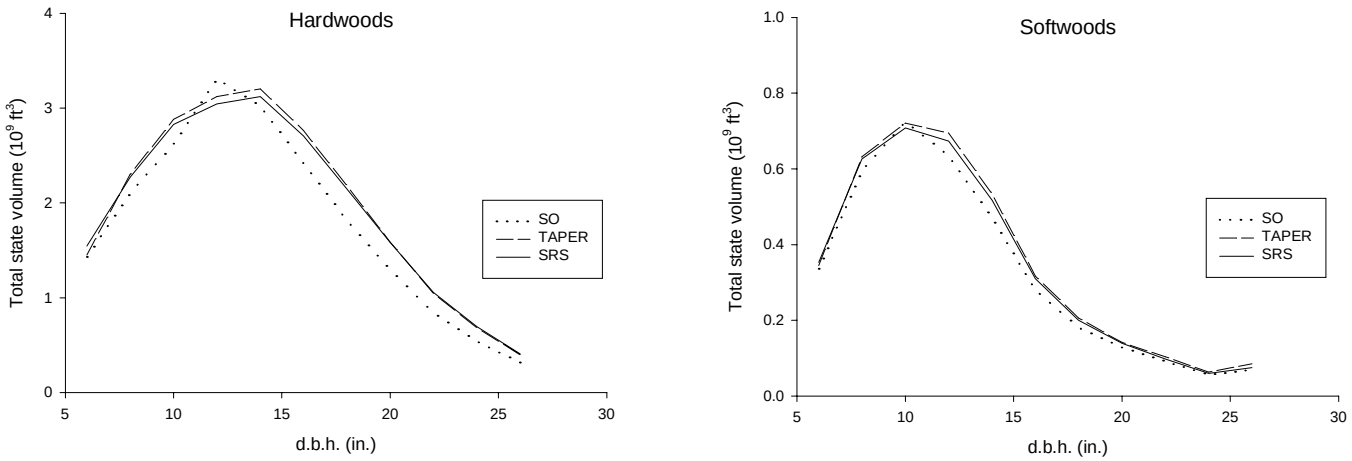

Figure 2—Total State volume for the 1999 Tennessee survey.

SRS method estimates are very similar for hardwoods, but the SO estimate deviates substantially, especially at larger d.b.h. The results of all three methods are similar for softwoods; SRS and TAPER are nearly the same.

The SRS estimates are very close to those of the original 1999 Tennessee survey because the identical methodology was used. The total State gross cubic foot volume estimate for the SRS method was 26.081 by 10^9 cubic feet; in table 19, Schweitzer (2000) listed 26.287 by 10^9. This minor discrepancy of less than 1 percent is probably due to a slightly different grouping of species.

Because the true volume is an unknown, it is impossible to determine which of the three methods provides the best approximation. Although comparisons were made with respect to the SRS as the standard, this was only done for convenience and does not imply any more confidence in this method. Generally, the SO method underestimates volume by about 8 percent as compared to the other two methods, which produce virtually identical results. The SRS method is composed of a much simpler set of volume equations than the TAPER method, but it is restrictive in that it is useful only for a fixed stump and upper d.o.b. limit. Although the TAPER method is initially more complex, once it is developed

and programmed into a computer, it has the flexibility to give estimates to any merchantability limit. Hence, it is believed that comparison of future estimates based on either the SRS or TAPER methods to the 1999 Tennessee survey should reflect changes in the forest resource and not changes in methodology.

Literature Cited

Schweitzer, C. J. 2000. Forest statistics for Tennessee, 1999. Resour. Bull. SRS-52. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station. 78 p.

Souter, R.A.; Clark, A.; Zarnoch, S.J. [In press]. Southern tree species stem taper and volume prediction equations. Res. Pap. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southern Research Station.

Spurr, S.H. 1952. Forest inventory. New York: The Ronald Press Co. 476 p.

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