1/95 has a larger specification for minimum circumference 6 ft from the butt of the pole than a tree classed as 2/95. If the pole length is 20 ft and the dbh is 7.7 in., the pole class would be estimated as 6/20 using Table 2 and as 7/20 using Table 3. A tree classed as a 7/20 has a smaller specification for minimum circumference 6 ft from the butt of the pole than a tree classed as a 6/20. When the dbh is close to 11 in., there is little difference between the tables. □

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Assessing Timber Availability in Upland Hardwood Forests

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ABSTRACT. Reported forest inventory statistics gathered by the USDA Forest Service, Southern Forest Experiment Station, Forest Inventory and Analysis (SOFIA) have been criticized because not all of the inventory volume reported is truly available for harvest. In response to this criticism, a procedure has been developed for assessing timber availability from reported inventory statistics for upland hardwood forests. The procedure uses forest inventory and ownership statistics gathered by SOFIA, a stump-to-mill cost prediction model developed by the USDA Forest Service, Northeastern Forest Experiment Station, and published wood price reports. Under the specific assumptions and conditions set forth in a demonstration of the procedure, a quarter of Tennessee's reported upland hardwood forest, containing about 40% of the reported inventory volume, was estimated to be available for harvest. The usefulness of the procedure in assessing available timber supplies for individual mills was also demonstrated.

South. J. Appl. For. 16(2):82–88.

The Forest Inventory and Analysis unit of the USDA, Forest Service, Southern Forest Experiment Station (SOFIA) conducts continuing surveys of the forest resources in seven Midsouth states (Alabama, Arkansas, Louisiana, Mississippi, Oklahoma, Tennessee, and Texas). The forest resources of each state are periodically assessed from permanent sample plots systematically located across each state on a 3 × 3 mile grid. At each forested sample plot, trees are tallied, their physical characteristics are measured, and a description of the plot location is made. From these data SOFIA derives the usual forest inventory statistics (area, volume, growth, and removals) and publishes them as standard tables in resource bulletins. Although these forest inventory statistics are eagerly awaited and widely used, one criticism often levied is that not all of the wood volume reported is truly available for harvest.

The factors affecting wood availability are numerous (legal restrictions, market conditions, operability constraints, and landowner attitudes) and their impacts are difficult to assess. Nevertheless, these factors must be taken into consideration if reasonable assessments of potential timber supplies are to be made from reported inventory statistics. Fortunately, a procedure for doing this has been developed for upland hardwood forests (includes SOFIA oak-hickory and maple-beech-birch forest type groups) and will be demonstrated using reported inventory statistics for Tennessee's expansive upland hardwood resource (Figure 1).

In Tennessee, a substantial difference exists between the reported and available inventories of the upland hardwood resource (Table 1). This difference is due to discounting the reported inventory for the impacts of each of the factors affecting wood availability as determined below.

Figure 1. Distribution of SOFIA sample plots located in upland hardwood forests, Tennessee, 1989.

Table 1. Estimated area and volume of upland hardwood forests available for harvest using conventional logging systems under average wood price and landowner attitude assumptions, Tennessee, 1989.

Inventory attribute	Unit of measure	Reported inventory	Profitable-to-log inventory	Percent reported	Available inventory	Percent reported
Timberland	Thousand acres	9,587.9	4,912.7	51	2,572.2	27
Growing-stock volume	Million cu. ft.	12,138.1	8,822.1	73	4,715.2	39
Sawtimber volume	Million bd. ft.[1]	39,363.4	31,988.6	81	17,193.7	44

[1] International ¼-inch rule.

LEGAL RESTRICTIONS

The SOFIA reports about 9.6 million ac of upland hardwood forests in Tennessee that are classified as timberland (forests at least 1 ac in size and capable of commercial timber production). Inherent in this timberland estimate is a discounting for forests that are incapable of commercial timber production. In Tennessee, a quarter-million acres have been excluded from the timberland estimate because they were withdrawn from commercial timber production by legislative mandate. The bulk of these are in wilderness reserves on public lands.

ECONOMIC CONSTRAINTS

The combined effects of market conditions and operability constraints can be mirrored in an assessment of the profitability of logging Tennessee's upland hardwood timberland. The determination of profitability is based on a comparison of costs and revenues associated with harvesting wood from upland hardwood stands and delivering it to the nearest wood-using mill. The costs and revenues are derived from wood price reports and cost predictions based on the size and volume of harvested wood, the distance the wood was hauled, and production functions of conventional logging systems working under typical logging conditions.

Profitability Model

The basis for the profitability determination is the ECOST model, initially developed by the USDA Forest Service, Northeastern Forest Experiment Station, to predict the stump-to-mill cost of cable logging in mountainous hardwood forests in the East (LeDoux 1985). It has since been expanded (ECOST version 2) to include ground-based logging of upland hardwood forests on more gentle terrain (LeDoux 1988). This model calculates the costs of felling, limbing, and bucking, skidding/yarding, loading, and hauling wood from the stump to the

Table 2. Model inputs and economic assumptions for assessing timber availability in Tennessee, 1989.

Inputs/assumptions	Unit of measure	Source
Harvest volume	ft^3/ac	User defined-SOFIA inventory data
Average harvest tree size—dbh	in.	User defined-SOFIA inventory data
Logging system	John Deere 540B	ECOST ver. 2 selection option: Appalacian Thinner Berger 25Y Bitteroot Clearwater Ecologger John Deere 540B Koller K-300 Radiohorse 9 Skylok 78 Urus 1000-3
Average skidding/ yarding distance	ft	User defined-Tennessee Division of Forestry
Truck class	3	ECOST ver. 2 selection option: 5—Flatbed, 4 × 2, single axis 4—Flatbed, 6 × 4, tandem axle 3—Truck tractor, 4 × 2, single axle with tandem trailer 2—Truck tractor, 6 × 4, tandem axle with tandem 30–35 trailer w/additional 15–20 trailer 1—Truck tractor, 4 × 2, tandem axle with tandem 30–35 foot trailer with additional 15–20 foot trailer
Haul distance	mi	User defined-SOFIA plot/mill community locations. SOFIA plot locations accurate to within one mile.
Road class	2,6	ECOST ver. 2 selection option: Design speed (mph) 2— 35 3— 25 4— 16 5— 8 6— 4
Delay cost	$/ft^3$	User defined-0.02 $/ft^3$
Move in/out cost	$/ft^3$	User defined-0.02 $/ft^3$
Stumpage cost Low Medium High	$/ft^3$	Timber-Mart South, Inc. 0.22 $/ft^3$ 0.35 $/ft.^3$ 0.46 $/ft.^3$
Delivered price	$/ft^3$	Tennessee Forest Products Bulletin-0.73 $/ft.^3$

Table 3. Estimated area and volume of upland hardwood forests profitable to log by delivered cost class, Tennessee, 1989.

Inventory attributes	Unit of measure	Reported inventory	Profitable-to-log inventory					
			Low cost	Percent reported	Medium cost	Percent reported	High cost	Percent reported
Timberland	M ac	9,587.9	6,867.6	72	4,912.7	51	1,626.0	17
Growing-stock volume	mm ft^3	12,138.1	10,877.1	90	8,822.1	73	3,740.0	31
Sawtimber volume	mm bf[1]	39,363.4	36,949.1	94	31,988.6	81	15,943.4	41

[1] International ¼-inch rule.

mill using equations derived from time studies and simulations of logging operations working in conditions typically encountered in upland hardwood forests.

Model Inputs

For the demonstration, the model inputs (Table 2) were set to represent logging conditions and systems relative to those typically encountered in Tennessee's upland hardwood forests and took the following form:

- Harvest volume—represented by the growing-stock volume on each SOFIA sample plot in Tennessee's upland hardwood forest. Growing-stock volume is the cubic-foot volume from a 1 ft stump to a 4 in. top, or point where the main stem breaks into limbs, for trees 5 in. dbh and larger that are capable of producing sawlogs, currently or prospectively. In reality, some growing-stock volume remains after harvest and some nongrowing-stock volume, contained in trees too rough or rotten to meet the growing-stock standard, is removed. However, growing-stock volume is the volume routinely reported in SOFIA resource bulletins, against which the criticism has been levied and availability assessments will be made.
- Harvest tree size—represented by the average dbh of all growing-stock trees (5 in. dbh and larger) on each selected SOFIA sample plot.
- Logging system—the ECOST version 2 model currently allows a choice of one of several ground or cable-based logging systems. The John Deere 540B[1] rubber-tired

[1] The use of trade, firm, or corporation names in this paper is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

Table 4. Average characteristics of upland hardwood forests profitable to log by delivered cost class, Tennessee, 1989.

Inventory attributes	Unit of measure	Reported inventory averages	Profitable-to-log inventory		
			Low cost averages	Medium cost averages	High cost averages
Growing-stock volume	ft^3/ac	1,266.0	1,583.8	1,795.8	2,300.1
Sawtimber volume	bf/ac[1]	4,105.5	5,380.2	6,511.5	9,805.4
Average diameter	in.	9.5	10.2	10.7	12.1
Stump-to-mill cost	$/$ft^3$	0.36	0.31	0.28	0.23
Profit	$/$ft^3$	—	0.20	0.10	0.04
Distance to mill	mi	5.9	5.8	5.7	5.5

[1] International ¼-inch rule.

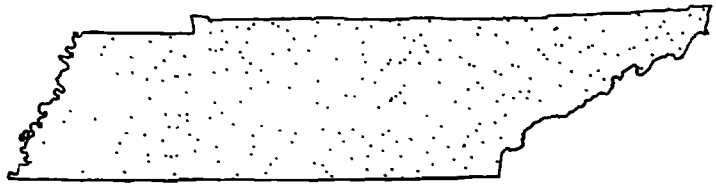

Figure 2. Distribution of communities with at least one primary wood-using mill, Tennessee, 1989.

Table 5. Estimated area and volume of upland hardwood forests profitable to log at medium cost by profit class, Tennessee, 1989.

Inventory attributes	Unit of measure	Profitable-to-log inventory	Profit Class ($/$ft^3$)		
			0.0–0.08	0.08–0.16	0.16–0.24
Timberland	mac	4,912.7	2,281.1	2,188.1	443.4
Growing-stock volume	mm ft^3	8,822.1	3,254.8	4,370.0	1,197.4
Sawtimber volume	mm bf[1]	31,988.6	9,810.3	16,484.9	5,693.4

[1] International ¼-inch rule.

Table 6. Average characteristics of upland hardwood forests profitable to log at medium cost by profit class, Tennessee, 1989

Inventory attributes	Unit of measure	Profitable-to-log inventory averages	Profit Class Averages ($/$ft^3$)		
			0.0–0.08	0.08–0.16	0.16–0.24
Growing-stock volume	ft^3/ac	1,795.8	1,426.9	1,997.1	2,700.2
Sawtimber volume	bf/ac[1]	6,511.5	4,300.7	7,533.7	12,839.4
Average diameter	in.	10.7	9.8	11.0	13.8
Stump-to-mill cost	$/$ft^3$	0.28	0.34	0.26	0.20
Profit	$/$ft^3$	0.10	0.04	0.12	0.18
Distance to mill	mi	5.7	6.1	5.4	5.2

[1] International ¼-inch rule.

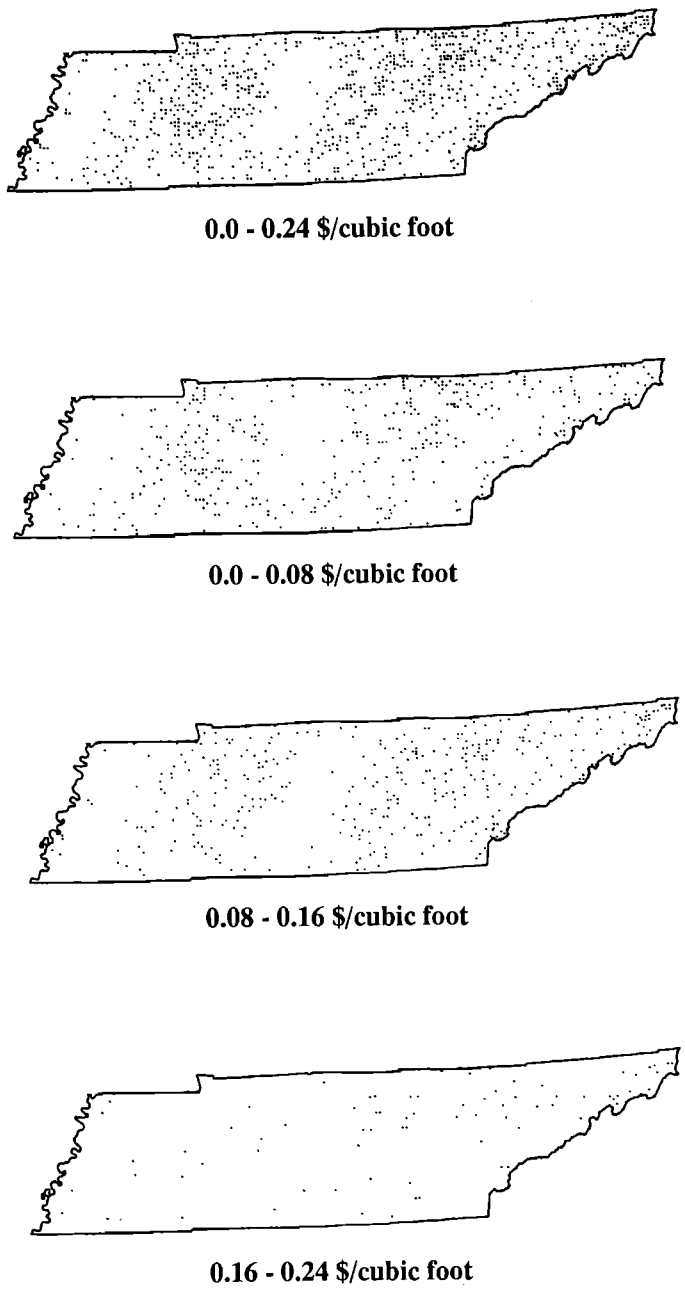

Figure 3. Distribution of upland hardwood SOFIA sample plots that are profitable to log at medium cost by profit margin classes, Tennessee, 1989.

skidder option was considered representative of the logging systems most commonly operating in Tennessee's upland hardwood forests.

- Average skidding/yarding distance—set at 500 ft and based on the average harvest tract size in Tennessee, estimated at 35 ac by the Tennessee Division of Forestry.
- Truck class—the ECOST version 2 model currently allows a choice of five truck classes. Class 3 was considered representative of the trucks hauling wood in Tennessee.
- Haul distance—defined as the mileage equivalent of the straight line distance between each selected SOFIA sample plot and the closest Tennessee community with at least one primary wood-using mill. In reality, wood may not always be delivered to the closest mill community and almost never via a straight delivery route. This approach does, however, recognize the number and location of markets in relation to the resource and should provide meaningful assessments of the relative availability of upland hardwood forests across the state, although the actual estimated area and volume may be optimized.
- Road class–the ECOST version 2 model currently allows a choice of five road classes, which are determined by the design speed of the roads. Haul distance was divided into two road classes. The slowest road class was assigned to the distance from each selected SOFIA sample plot to the nearest all-weather road (one of the plot location description variables collected by SOFIA) as an estimate of the "pull" road that would have to be constructed to access the timber. The remainder of the haul distance (after subtracting pull road distance) was assigned to road class 2, deemed representative of the average trucking speed on Tennessee's state roads.
- Delay cost—an estimate, based on the user's knowledge of the logging system, of the unproductive time in all aspects of harvesting and delivering wood to a mill. Set at 0.02 $/ft^3$ of harvest volume for this demonstration.
- Move cost—an estimate, based on the user's knowledge of the logging system, of the cost associated with moving equipment into, out of, or within the harvest tract. Set at 0.02 $/ft^3$ of harvest volume for this demonstration.

Based on these inputs, the model predicted the stump-to-mill cost (in 1984 dollars/ft^3 removed) of logging the growing-stock volume of each selected SOFIA sample plot. To this cost was added the cost of growing the harvested wood, reflected in the average low,

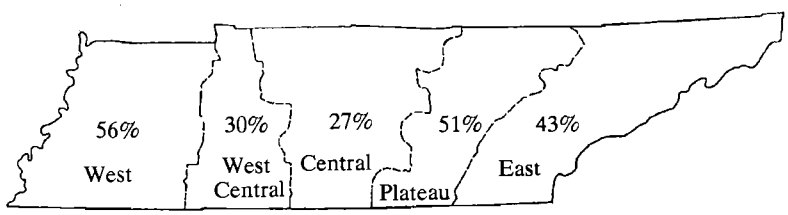

Figure 4. Percent of profitable-to-log upland hardwood timberland owned by other private owners willing to harvest timber by SOFIA survey region, Tennessee, 1989.

Table 7. Estimated area and volume of upland hardwood forests available for harvest by SOFIA survey region, Tennessee, 1989.

Inventory attributes	Unit of measure	SOFIA survey region	Reported inventory	Profitable-to-log inventory	Percent reported	Available inventory	Percent reported	Available inventory percent sampling error
Timberland	mac	West	1,102.1	634.7	58	368.4	33	1.8
		West-central	2,030.9	821.0	40	396.8	20	1.7
		Central	1,940.5	878.2	45	285.0	15	2.1
		Plateau	2,301.9	1,229.7	53	726.5	32	1.3
		East	2,212.6	1,349.0	61	795.4	36	1.2
		State	9,587.9	4,912.7	51	2,572.2	27	0.7
Growing-stock volume	mm ft^3	West	1,465.2	1,145.1	78	666.1	45	7.0
		West-central	2,250.4	1,341.6	60	603.3	27	7.4
		Central	2,163.0	1,499.5	69	478.9	22	8.3
		Plateau	3,057.1	2,237.1	73	1,342.4	44	4.9
		East	3,202.4	2,598.8	81	1,617.4	51	4.5
		State	12,138.1	8,822.1	73	4,715.2	39	2.6
Sawtimber volume	mm bf[1]	West	5,040.9	4,227.7	84	2,457.6	49	9.3
		West-central	6,197.3	4,372.3	71	2,113.6	34	10.1
		Central	6,742.1	5,316.4	79	1,567.3	23	11.7
		Plateau	10,124.6	8,167.7	81	4,938.8	49	6.6
		East	11,258.5	9,904.5	88	6,191.2	55	5.9
		State	39,363.4	31,988.6	81	17,193.7	44	3.5

[1] International ¼-inch rule.

medium, and high stumpage prices paid in Tennessee (Timber-Mart South, 1984). These average stumpage prices were weighted by the species, grade, and product distribution of Tennessee's latest timber harvest figures to account for the diversity in the state's primary forest products industry. Together, stump-to-mill and stumpage costs provided estimates of the total cost of delivering wood from each plot to the nearest mill community.

The delivered cost estimates were compared to the average price paid for wood by Tennessee's primary wood-using mills (Tennessee Division of Forestry 1984), which had also been weighted by the species, grade, and product distribution of Tennessee's timber product harvest. If delivered price exceeded delivered cost, the wood from the SOFIA sample plot was considered profitable to log. Conversely, the plot was considered unprofitable to log if the opposite was true.

Profitable-to-Log Inventory

Expanding the sample of profitable-to-log plots (each plot represents, on average, 5,760 ac of timberland) resulted in an estimate of the area and volume of Tennessee's upland hardwood forest that could be profitably logged (Table 3). As expected, increases in delivered costs caused by higher stumpage fees resulted in fewer acres and less volume being classed as profitable to log because only stands of increasingly better quality were capable of being profitably logged, and such stands occur relatively infrequently in the state's inventory. Also, there was a compensating cost-saving associated with logging the better quality stands (stands with higher volume and larger trees) that served to reduce stump-to-mill costs and help offset the stumpage cost increases (Table 4). Although partially offset by improved stand quality, stumpage was a major, if not the major, cost of delivering wood to the mill and had a major influence on the profitable-to-log inventories and their profit margins. Haul distance also factored into the profitability determination but because of the 250 or so widely dispersed mill communities in Tennessee (Figure 2), its impacts were lessened, although still evident in the decreasing haul distance associated with increasing delivered costs (Table 4).

The logical nature of all of these relationships gives credence to the results, which show that half of Tennessee's upland hardwood timberland, containing roughly three-quarters of the reported volume, could be profitably logged at the medium delivered cost estimate (Table 3). However, the profit margins (differences in delivered prices and costs) of these acres are quite variable ranging up to 0.24 \$/ft^3 harvested, with the bulk of the acres returning less

Table 8. Comparison of reported growth and available growth to reported removals for upland hardwood forests, Tennessee, 1989.

Inventory attributes	Unit of measure	Reported growth	Available growth	Reported removals
Growing-stock volume	mm ft^3/yr	387.6	159.9	169.2
Sawtimber volume	mm bf/yr[1]	1,850.2	771.8	672.4

[1] International ¼-inch rule.

Table 9. Estimated area and volume of upland hardwood forests available to fictitious mill site in Tennessee, 1989.

Inventory attributes	Unit of measure	Reported inventory	Profitable-to-log inventory	Percent reported	Available inventory	Percent reported
Timberland	m ac	3,584.4	846.0	24	397.6	11
Growing-stock volume	mm ft^3	4,826.8	1,843.5	38	892.5	18
Sawtimber volume	mm bf[1]	16,187.5	7,521.0	46	3,743.9	23

[1] International ¼-inch rule.

than 0.16 $/$ft^3$ harvested (Table 5). Much of the variation in profit can be explained by the interactions of stand quality and haul distance on stump-to-mill costs (Table 6). Generally, the distribution of these profitable-to-log acres becomes more dispersed as profit margins increase, reflecting the low frequency and scattered nature of the better quality stands in the state (Figure 3). Overall, a vast amount of wood is capable of paying its way out of the woods, which suggests a maturing forest that has great potential for increased utilization, assuming the timber owners are willing to sell it.

LANDOWNER ATTITUDES

Of course, not all owners of profitable-to-log timberland are willing to harvest timber, and therefore the profitable inventory must be discounted to account for these owners. For the demonstration, it was assumed that timber harvesting would occur on forest industry timberland and that timber production would remain one of the multiple benefits derived from public timberland. However, most of Tennessee's upland hardwood timberland is in other private ownership, an ownership group of diverse owners with varying ownership objectives, of which timber production is one of many and not necessarily the primary one. Consequently, this ownership group has been the subject of several studies (Wells 1977, Wiggins 1977, Baird and Doolittle 1990) to determine the willingness of these landowners to sell or not sell timber and the reasons for their decisions.

Based on the latest of these studies, timber on about 42% of the profitable-to-log timberland owned by other private owners will be offered for sale in the near future. The willingness of these owners to sell timber varies across the state with owners in the central and west-central regions of the state only about half as willing to sell timber as those in the other survey regions of the state (Figure 4). Applying these regional percentages to the profitable-to-log inventory held by other private owners in each region, adding in the entire profitable-to-log inventory on forest industry and public timberlands, and assuming that the landowners willing to sell would do so at the average stumpage price used in the demonstration, resulted in the final available inventory estimate for Tennessee's upland hardwood forests.

In total, about a quarter of the timberland, containing about 40% of the reported inventory volume, was estimated to be available for harvest (Table 1). Because of the poorer condition (volume and tree size) of upland hardwood timberland in the central and west-central regions of the state and the unwillingness of owners to sell timber in these regions, the available inventory has been shifted to the other survey regions in the eastern and western ends of the state relative to the reported inventory (Table 7).

It is the available inventory that must supply the harvest demands placed upon the state's upland hardwood resource, not the much larger reported inventory. Although smaller, the available inventory is essentially capable of meeting the harvest demands, but its growth-to-removals ratio is not nearly as favorable as that of the reported inventory (Table 8). The magnitude of the differences between the reported and available inventories emphasizes the importance of accounting for the factors affecting availability when assessing timber supplies from reported inventory statistics.

MILL STUDIES

In addition to indicating the relative availability of upland hardwood forests across large areas, the procedure described above can also be used to help define wood procurement zones and available timber supplies for individual mills. To do this, haul distance must be redefined as the distance from each SOFIA sample plot to a given mill rather than the distance to the closest mill community, and the willingness-to-sell assumptions must be reassessed. Once done, the procedure can estimate the area, volume, and distribution of wood that can be purchased and profitably harvested off upland hardwood timberland and delivered to the mill location.

For example, Table 9 shows the reported, profitable, and available inventories for a fictitious mill in Tennessee. The quality (volume and tree size) of the profitable-to-log plots and their location relative

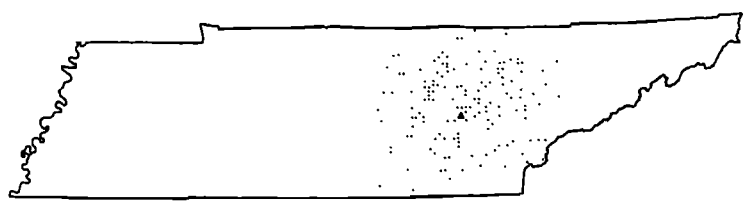

Figure 5. Distribution of profitable-to-log SOFIA sample plots around fictitious mill site (triangle), Tennessee, 1989.

Table 10. Average characteristics of upland hardwood forests that are profitable to log and deliver to a fictitous mill site at medium cost by distance class, Tennessee 1989.

Inventory attributes	Unit of measure	Distance Class (mi) 0–10	10–20	20–30	30–40	40–50	50–60	Averages 60–70	70–80
Timberland	m ac	51.7	119.8	151.1	239.0	141.3	115.1	17.0	11.1
Growing-stock volume	ft^3/ac	1,791.8	1,941.1	2,043.0	2,155.8	2,315.8	2,584.4	2,658.9	2,226.8
Sawtimber volume	bf/ac[1]	6,375.7	6,322.0	7,899.5	8,857.6	10,105.7	11,874.3	11,822.9	11,599.3
Average diameter	in.	10.0	10.1	11.3	11.7	11.9	13.0	14.8	16.2
Profit	$/$ft^3$	0.09	0.06	0.07	0.05	0.03	0.03	0.02	0.01
Stump-to-mill cost	$/$ft^3$	0.29	0.32	0.31	0.33	0.35	0.35	0.36	0.37

[1] International ¼-inch rule.

to the mill site set the outer limits of the mill's wood procurement zone, beyond which wood from SOFIA plots could not be profitably delivered to the mill site (Figure 5). Stand quality's role in defining the wood procurement zone is related to its effect on harvesting costs. As discussed in the previous example, improvements in stand quality reduce harvesting costs, which in this case help to defray hauling costs, extending the procurement zone limits. However, from Table 10 it is clear that hauling cost is a far more important component of the total cost of delivering wood to the mill than in the previous example, as evidenced by decreasing profit margins with increased hauling distance, despite improving stand quality. Overall, the juxtaposition of the profitable plots and the mill site resulted in a wood procurement zone that extends out 72 mi to encompass stands of exceptional quality. This maximum wood procurement limit also determined the radius for the circular resource area around the mill site that formed the basis for the mill's reported inventory.

The final available inventory estimate for the procurement zone resulted from discounting the profitable inventory for the 55% of other private owners unwilling to sell timber, and for the entire inventory owned by forest industries, all assumed to be competitors. Clearly, this procedure provides useful information for assessing timber supplies and locations for individual mills.

CONCLUSION

A procedure has been demonstrated for assessing timber availability from reported inventory statistics for upland hardwood forests. Although the results are only applicable to the conditions defined by the model input variables and other assumptions, it has been demonstrated that with minor modifications to the initial conditions, both statewide and site-specific assessments of availability are possible. Such flexibility expands the utility of the procedure by allowing users to tailor initial conditions to meet specific needs.

In addition, developing geographic information systems (GIS) offers the possibility of assisting in tailoring efforts by refining many of the model input variables. For example, with better spatial analyses it should be possible to estimate actual haul miles and road classes between SOFIA plots and mill locations as well as provide better assessments of the impacts of legislative restrictions on timber availability by enumerating areas within protective corridors along water bodies or roads. Overall, the procedure demonstrated goes a long way toward addressing the perceived shortcoming in SOFIA inventory statistics, especially since the procedure can be readily applied to upland hardwood inventory statistics reported for other states and is so easily modified to meet site- or user-specific needs. □

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