INTEGRATING FOREST GROWTH AND HARVESTING COST MODELS TO IMPROVE FOREST MANAGEMENT PLANNING

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Abstract: Two methods of estimating harvesting revenue -- reported stumpage prices - and delivered prices minus estimated harvesting and haul costs were compared by estimating entry cash flows and rotation net present value for three simulated even-aged forest management options that included 1 to 3 thinnings over a 90 year rotation. Revenue estimates derived from stumpage prices indicated that all thinnings were economically feasible and that net present value was maximized by initiating thinning at age 40. Revenue estimates derived from estimated harvesting costs and delivered prices revealed that thinning at age 40 yielded the lowest net present value due to high harvesting costs and negative first-entry cash flows. Stumpage-based revenue estimates also were very unstable and highly dependent upon the sawtimber utilization assumptions of the economic analysis. The results show that integrating harvesting cost models with growth-and-yield simulators can provide more stable and reliable revenue estimates over the wide range of harvesting conditions required to evaluate forest management alternatives.

INTRODUCTION

The recent development of mathematical forest growth-and-yield models has provided researchers and forest managers with very powerful and versatile tools. Models applicable to eastern hardwoods include: FIBER, OAKSIM, TWIGS, SILVAH, and STEMS (Shifley 1987). One application of these computer models is regional inventory projections (Solomon and Hosmer 1987). Another application of growth-and-yield projections, and the focus of this paper, is the economic analysis of forest management alternatives. Several of the available growth-and-yield models have been utilized to evaluate management practices such as precommercial and commercial thinnings; comparing economic returns resulting from these practices with returns from the no-thin option (Risbrudt and Pitcher 1986). This and numerous other studies have evaluated forest management alternatives by applying reported stumpage prices to projected product yields. Because stumpage prices are an integral part of those economic analyses, it is important to identify potential limitations of stumpage-price applications and to define a more reliable alternative.

Stumpage prices represent the unit price paid to forest-land owners for standing timber. The mean or median and range of prices for each tree species are reported for a state or

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geographical regions within a state (Ohio Agric. Stat. Serv. 1989, Pa. State Univ. 1988). The price range reported for each tree species generally indicates that stumpage prices are extremely variable. Consequently, published price reports often caution users that average prices reflect only market trends and largely ignore the harvest tract attributes that affect stumpage prices. These attributes include tree size, species composition, tree quality, volume harvested per acre, tract volume, accessibility, and distance to roundwood markets. As a result, reported average stumpage prices are adjusted so that prevailing regional or local harvesting and market conditions are reflected in the stumpage price paid for a specific tract.

Valuable insight regarding the application of reported stumpage prices can be obtained from the surveys of nonindustrial private forest-land (NIPF) owners conducted in four major hardwood producing states: Kentucky (Birch and Powell 1978), Ohio (Birch 1979), Pennsylvania (Birch and Dennis 1980), and West Virginia (Birch and Kingsley 1978). These survey results define the source of stumpage prices with respect to the attributes of the NIPF timber harvests representing most of the reported prices. Collectively, these surveys indicate that NIPF harvests are cash-flow oriented with little concern for silvicultural treatments. Results also indicate that sawlogs and veneer logs are the products of primary interest; that diameter limit and selection cutting account for half of the acres harvested; and that foresters are involved in tree selection on only 9 to 32 percent of the acres harvested. The harvests described often equate to high grading, or removing only the most valuable timber. Accordingly, average reported stumpage prices probably reflect the least costly method of obtaining the most valuable sawtimber.

If the average stumpage prices applied are not sensitive to stand attributes and harvesting practices, their application to the economic analysis could introduce substantial error. Prices derived from prevailing harvesting practices may not be consistent with the tree selection and wood utilization assumptions of a specific growth-and-yield projection. This can be very important when the growth-and-yield projections include thinnings in young stands, or removal of low-quality growing stock in regeneration cuts. Furthermore, applying constant stumpage prices to all scheduled entries largely ignores harvesting cost trends that have been documented for ground-based systems (Stuart 1982) and for cable-yarding systems (LeDoux 1987). These and other studies show harvesting costs decreasing with increasing tree volume and volume per acre. This trend is particularly important when growth projections include revenue estimates from early thinning, which are costly to harvest.

The objective of this study was to compare two methods of estimating net revenue from thinning and regeneration entries. One method applied reported stumpage prices. The other method estimated revenue as the residual of reported delivered-product prices minus estimated harvesting and hauling costs. This residual is often termed conversion return or conversion surplus. Comparisons include entry cash flows and the net present value (NPV) ranking of selected forest management options. These comparisons were conducted to determine the effects of stand age, harvesting conditions, and sawtimber utilization practices on estimated harvesting revenue.

METHODS

The revenue analysis utilized stand tables representing trees harvested from thinnings at ages 40 to 70 years and even-aged regeneration cuts at age 90. The growth projections were made using the OAKSIM model (Hilt 1985) to simulate growth of even-aged upland oak stands on site index 70. The initial stand table represented a fully-stocked upland oak stand at age 40 (Schnur 1937). The three even-aged forest management options compared were:

Forest Management option	Thinning	Regeneration
	----------- Age (years)	--------------
1	40,55,70	90
2	50,70	90
3	60	90

These options were selected to provide variable ages at first thinning and number of thinnings, yet conform to the 50-year projection-period constraint imposed by the OAKSIM model. All simulated thinnings reduced residual stocking to 60 percent of full stocking.

Costs and revenues were estimated for each scheduled entry using a computer program to simulate the timber harvesting operation and to estimate product yields (Baumgras 1990). This program performs two primary functions: (1) simulation of the harvesting system production rate, and (2) estimation of product yields that include factory grade sawlogs, sawbolts, and pulpwood-fuelwood. The production-rate estimates provide information required to predict stump-to-truck harvesting costs. The product-yield estimates are the basis of revenue estimates.

The timber harvesting simulation is a stochastic process that applies logging-machine-cycle time equations and delay-time distributions developed from time-and-motion study data collected in West Virginia. Machine production is modeled as a function of cut stand attributes. System production is modeled as a function of system component production to reflect system interactions. The simulated system included manual chainsaw felling with two saw operators, one mid-sized rubber-tired skidder, and a loader-slasher combination to handle bucking, sorting, and truck loading.

The simulated harvesting assumed a 50-acre tract with a maximum skid distance of 1,600 feet and a 200-foot spacing between parallel skid roads. To satisfy silvicultural objectives, all cut trees 3 inches diameter at breast height (dbh) and larger in the cut-stand tables obtained from OAKSIM were felled in each thinning or regeneration entry. However, only trees 8 inches dbh and larger were skidded and utilized. Cost rates required to estimate harvesting costs from simulated production times were based on 1989 wage rates sampled from West Virginia loggers ($6.50/hour to $8/hour plus 33 percent payroll costs) and machine investment requirements and operating costs reported by Burgess and Cubbage (1988). The resulting harvesting-cost estimates represent the cash flow required by the logger to cover all expenses and to provide an after-tax cash flow to cover capital investment plus a 12-percent return on invested capital.

The harvesting simulation did not include trucking. Instead, estimated trucking costs were deducted from delivered prices. Trucking costs were estimated from rates published by Koger (1981), which were updated using current truck machine rates (Burgess and Cubbage 1988). Hauling cost estimates were based on a tractor-trailer combination hauling 1 mile over woods roads, 2 miles over gravel roads and the balance over 2 lane-paved roads. To estimate the impact of haul distance on net revenue, the analysis included one-way haul distances of 15, 30, and 60 miles.

The procedure for estimating product yields employs tree taper functions developed for Appalachian hardwood tree species (Martin 1981). The procedure also estimates sawlog volume by USDA Forest Service factory log grades by applying the sets of equations developed by Yaussey and others (1988), together with equations for estimating tree grade distributions by species and dbh developed for oak stands from Pennsylvania forest survey data (Dale and Brisbin 1985). Estimated sawlog volume included only logs with a scaling diameter 10 inches diameter inside bark (dib) and larger, a limit imposed by many mills that saw grade lumber. The primary analysis also imposed a 14-inch dbh limit on sawtimber trees, with limits of 12 to 15 inches tested in a sensitivity analysis.

The stumpage prices and prices paid for delivered roundwood are based on 1988 prices reported for Ohio (Ohio Agric. Stat. Serv. 1989) and Pennsylvania (Pa. State Univ. 1988). These two sources report stumpage price by species and delivered prices by species and grade. Sawlog stumpage and delivered prices represent a simple average of 1988 Ohio and Pennsylvania prices (Table 1). Pulpwood prices include a delivered price of $45/100 ft^3 cubic feet of wood and bark (Ccf), approximately $15/ton; and a stumpage price of $6/Ccf, approximately $2/ton. The pulpwood prices also were obtained from the Ohio and Pennsylvania price reports and were consistent with other published price reports.

Net revenue derived from stumpage prices (NRSP) is the product of estimated product volume and stumpage prices, where sawlog prices and yields are based only on tree species. Net revenue estimates derived from delivered prices (NRDP) reflect species, grade, harvesting costs, and haul distances of 15 miles ($NRDP_{15}$), 30 miles ($NRDP_{30}$), and 60 miles ($NRDP_{60}$). Sawtimber net revenue is the product of estimated sawlog volume and reported delivered prices minus haul costs, where volume and price reflect both species and log grade. Haul costs also were deducted from delivered pulpwood price. To simplify the analysis it was assumed that pulpwood and sawlogs were hauled the same distance.

RESULTS

The following comparisons define the potential limitations of stumpage prices when cash flows are affected by harvesting cost trends, haul costs, and sawtimber utilization practices.

These results also demonstrated the potential advantages of integrating harvesting cost models with forest growth-and-yield models to improve revenue estimates.

Table 1.--Average reported sawtimber stumpage prices and prices paid for sawlogs delivered to sawmills; for Ohio and Pennsylvania in 1988.

Tree species	Stumpage[1] price	Delivered price log grade[2] 1	2	3
		$/Mbf, Int. 1/4		
White oak	158	341	180	95
Red oak	234	412	238	104
Others[3]	80	160	109	86

[1]Reported only by tree species.
[2]USDA Forest Service factory log grades.
[3]Includes yellow-poplar and red maple.

Stand Attributes and Harvesting Cost

Important differences between thinning and regeneration entries are demonstrated by the cut-stand attributes and harvesting costs estimated for each entry (Table 2). The differences in harvesting costs largely can be attributed to total volume harvested and average merchantable volume per tree, with larger trees and heavier removals resulting in lower costs. Because of this, the timing of the first thinning is very important. Estimated first-entry stump-to-truck costs range from $59/Ccf at age 40, to $34/Ccf at age 60. Postponing of thinning for 20 years, until age 60, permitted total volume harvested to increase from 3.5 Ccf/acre to 10.1 Ccf/acre. Average volume per tree increased from 10.9 ft^3 to 16.0 ft^3 (Table 2).

Successive thinning entries of forest management options 1 and 2 also show significant harvesting cost reductions. Under option 1 estimated harvesting costs decline from $59/Ccf at age 40 to $28/Ccf at age 70 (Table 2). In contrast, harvesting cost estimates were very similar for all three regeneration entries.

The results presented in Table 2 demonstrate very important harvesting cost trends that affect potential harvesting revenue from thinning versus regeneration entries. These cost estimates are a function of the equations and distributions incorporated into the simulation model and the cost rates applied to the simulation results. Because these entries are subject to variation, the results are also variable. However, more important than the estimated cost levels are the trends that indicate cost reductions and potential revenue gains with increasing age and volume, results supported by numerous harvesting studies.

Table 2.--Simulated cut stand attributes and stump-to-truck harvesting costs for each entry tested.

Forest mgt. option	Harvesting entry[1]	Volume harvested[2] Total	Average tree	Cost
	- type-age -	- Ccf/ac. -	- ft^3 -	- $/Ccf -
1	T-40	3.5	10.9	59
	T-55	4.2	15.6	38
	T-70	5.3	23.9	28
	R-90	35.7	33.3	18
2	T-50	6.9	13.5	41
	T-70	6.8	21.2	30
	R-90	35.5	32.0	18
3	T-60	10.1	16.0	34
	R-90	37.4	29.4	20

[1]Thinning = T, Regeneration = R, age = years
[2]Trees 8-inches dbh and larger to a 4-inch top dib.

Cash Flow

The variations in estimated harvesting costs are directly reflected in the comparisons of estimated net revenue (Table 3). Revenue estimates derived from average reported stumpage prices necessarily yield a positive cash flow. However, deducting estimated harvesting and haul costs from reported delivered prices yielded several negative cash flows. These include: all age 40 thinnings, thinning at age 55 with 60-mile haul, and first thinning at age 50 with 30- or 60-mile hauls (Table 3). These negative cash flows indicate that harvesting would not be economically feasible for the logger, and would require the landowner to subsidize the thinnings. Estimates of thinning revenue derived from average stumpage prices always were greater than or equal to estimates derived from delivered prices.

Table 3.--Estimated net revenue per entry by method of estimating revenue and haul distance.

Forest mgt. option	Entry[1]	Net revenue estimate[2]			
		NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	- Type-Age -	---------------- dollars/acre ----------------			
1	T-40	21	-59	-69	-83
	T-55	25	15	5	-12
	T-70	123	109	96	73
	R-90	1382	1417	1321	1152
2	T-50	41	7	-10	-38
	T-70	139	110	93	64
	R-90	1283	1360	1265	1100
3	T-60	85	85	60	18
	R-90	1247	1306	1206	1036

[1]Thinning = T, Regeneration = R, age = years
[2]NRSP = stumpage based estimate
NRDP = estimate based on delivered price, harvest cost, haul cost for hauls of 15, 30, and 60 miles.

Given the relatively low cost of harvesting large sawtimber and the NIPF survey results that indicate most stumpage prices are derived from sawtimber harvests, it is not surprising that the two methods of estimating revenue produced similar results from the three regeneration entries tested. At haul distances of 15 and 30 miles, the two types of revenue estimates differed by only 2.5 to 6.0 percent of the stumpage price estimate. Increasing haul distance to 60 miles results in significant revenue reductions for all entries, a variable not reflected in stumpage prices.

Net Present Value

To compare the net present value of each forest management option, all cash flows in Table 3 were discounted to time = 40 years, using a 4 percent real interest rate and constant product prices (Table 4). Age 40 represents the time the decision is made to thin at age 40 or to postpone thinning. However, the discount period affects only the magnitude of all NPV's, not the NPV ranking of forest management options. Were a management option selected, using the NPVs derived from stumpage prices, option 1 would be selected (Table 4). The positive cash flows from each entry and the increased final harvest revenue resulting from early thinning all favor option 1. By contrast, option 1 consistently yields the lowest ranking NPV when cash flows reflect varying harvesting and haul costs. These NPV's favor option 2 at haul distances of 15 and 30 miles, and option 3 when all products are hauled 60 miles. Furthermore, if the landowner is reluctant to invest in thinning and requires a positive cash flow from all entries, then management option 2 is also infeasible with a 30-mile haul because of the negative first-entry cash flow (Table 3).

Table 4.--Net present value of discounted harvesting cash flows for each forest management option, by method of estimating net revenue.

Forest mgt.	Source of revenue estimates			
Option	NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	NPV (dollars/acre)[1]			
1	268[2]	182	149	95
2	251	230[2]	200[2]	149
3	214	222	197	154[2]

[1]Net cash flows discounted to time = 40 years.
[2]Maximum NPV for method and haul distance.

These results indicate that the method of estimating harvesting cash flows can have a large impact on estimated NPV and forest management decisions. If we assume that the harvesting and hauling cost estimates are reasonably reliable, depending solely on stumpage prices and ignoring cost trends did not identify infeasible entries or the NPV-maximizing management options. Furthermore, ignoring harvesting cost trends implicitly assumes that the harvesting firm, not the landowner, absorbs the high cost of harvesting wood from early thinnings. Given the large supply of low-quality hardwoods, this is an unlikely scenario.

Sensitivity Analysis

The results in Tables 2 through 4 were developed applying a 14-inch dbh limit to sawtimber trees by calculating sawlog volumes only for trees 14 inches dbh and larger. Trees 8 to 13 inches dbh were utilized only for pulpwood. Although smaller trees can yield 8-inch dib grade-3 sawlogs, communications with several forest products utilization specialists in the northeast indicates that many sawmills manufacturing factory grade lumber buy only logs 10 or 12 inches dib and larger. To determine the impact of minimum sawtimber dbh on estimated revenue, dbh limits of 12 to 15 inches were evaluated with both revenue estimating methods. This comparison was conducted using the cut-stand table representing the regeneration harvest under management option 1.

Increasing the minimum sawtimber dbh reduced total sawlog volume from 9.1 Mbf/acre to 4.6 Mbf/acre, but increased the proportion of total sawlog volume in log grades 1 and 2 from 37 percent to 57 percent (Table 5). These results also show NRSP decreasing 40 percent in direct proportion to the sawlog volume reduction, declining from $1833/acre to $1093/acre (Table 5). Conversely, when decreasing the minimum sawtimber dbh from 15 to 12 inches the NRSP estimate assumes that the unit value of the incremental volume of small low-grade logs equals that of the larger sawlogs. NRSP applies the same unit value to all sawlog volume of a given species. $NRDP_{30}$ reflects both tree species and log grade. As a result, $NRDP_{30}$ decreased only 6.6 percent; from $1,349/acre to $1,258/acre (Table 5). Most of the sawlog volume reduction resulting from the increased minimum dbh was low-value grade 3 logs. When these logs are marketed as pulpwood, the relative reduction in $NRDP_{30}$ is much less than the relative reduction in sawlog volume.

Table 5.--Estimated sawlog volume harvested, percent of harvested sawlog volume by factory log grades, and net revenue by minimum sawtimber dbh. Results represent the regeneration entry under management option 1.

Minimum[1] sawtimber Dbh	Total sawlog volume	Log grades 1 and 2	Net revenue[2]	
			NRSP	$NRDP_{30}$
- Inches -	- Mbf/acre -	- Percent -	------ Dollars/acre ------	
12	9.1	37	1833	1349
13	7.9	42	1636	1345
14	6.2	50	1382	1321
15	4.6	57	1093	1258

[1]Trees smaller than minimum dbh are used only for pulpwood.
Total volume of pulpwood and sawlogs remains constant at 35.7 Ccf/acre.
[2]Harvesting cost is constant for all minimum dbh levels.

The implicit assumption of the stumpage-based estimate is that unit stumpage value is independent of wood utilization practices and the resulting log grade mix, or the wood utilization assumptions incorporated in the analysis are representative of the harvesting practices reflected in the reported stumpage prices. The large variation in NRSP estimates reflect the magnitude of the error that could result if these assumptions were invalid. For example, if reported stumpage prices reflected a 15-inch dbh limit, yet the economic analysis applied a 12-inch dbh limit with no unit price adjustment, the results would overestimate revenue by 68 percent. By comparison, the relative stability of $NRDP_{30}$ significantly lessens the impact of erroneous wood utilization assumptions (Table 5).

DISCUSSION

Both methods of projecting harvesting revenue are subject to the uncertainties affecting all economic forecasts. However, since stumpage prices represent actual landowner receipts, then these prices are conceptually a better estimator of expected revenue. Revenue estimates derived as the residual of delivered prices minus extraction costs represent only maximum stumpage payments consistent with estimated harvesting and hauling costs. Although conceptually superior, reported average stumpage prices appear to be reliable estimators only when applied to harvesting conditions and utilization practices similar to those prevalent in the stumpage price sample. When this is not the case, results indicate that large errors could occur. Whereas stumpage prices indicate that it is economically feasible to thin at ages 40 or 50 years, the inclusion of harvesting costs in the revenue estimate indicates that these thinnings could lose $10 to $83/acre (Table 3). Furthermore, erroneous assumptions regarding stumpage prices and prevalent sawtimber utilization practices could overestimate regeneration revenue by $740/acre (Table 5). In terms of cash flows, the differences in regeneration-cut revenues greatly exceed the differences in thinning revenues estimated by each method. However, the NPV effects of the two sources of error are similar.

The two methods of estimating revenue produced similar results when applied to regeneration entries and moderate haul distances, assuming a 14-inch dbh limit for sawtimber trees. This result can be interpreted as a validation of the NRDP estimates since landowner survey results indicate that stumpage prices are generally derived from sawtimber harvests, and grade lumber mills seldom utilize small grade 3 logs. For other harvesting conditions and utilization options, the large difference between revenue estimates demonstrates that estimates derived from average reported stumpage prices are insensitive to stand attributes and are very unstable over a range of sawtimber utilization options.

This research indicates that the application of delivered prices and estimated extraction costs can provide more stable and reliable revenue estimates over the wide range of harvest entries required to simulate economic returns to forest management alternatives. To reflect harvesting conditions accurately for each simulated entry, the cut stand attributes required to estimate harvesting cost can be obtained from the stand tables produced by the growth simulations. The stochastic harvesting simulation model applied in this study is not yet available. However, cost estimating programs currently available include EASTCOST (LeDoux unpub.), as well as the Auburn Harvesting Analyzer, the Harvest System Analyzer, and the Harvest System Simulator (Reisinger and others 1988). MANAGE (LeDoux 1986) is one of the few available forest planning models that integrates growth-and-yield results with detailed stump-to-mill cost estimates for eastern hardwoods.

To utilize fully the capabilities of growth-and-yield models it is important that developments in the economic analyses of forest management alternatives keep pace with the developments in growth-and-yield modeling. This requires harvesting revenue estimates that accurately reflect quality and value as well as volume, and that harvesting cost trends are an integral part of the economic analysis. Results presented demonstrate the potential effects of revenue estimation methodology on revenue estimates and management decisions. These results also indicate the importance of integrating harvesting cost models with growth-and-yield models to improve revenue estimates.

LITERATURE CITED

Baumgras, J. E. 1990. The effects of product markets and multiproduct harvesting on the economics of managing even-aged upland oak stands. Ph.D. dissertation. West Virginia University, Morgantown. 210 p.

Birch, T. W., and D. F. Dennis. 1980. The forest-land owners of Pennsylvania. USDA For. Serv. Resour. Bull. NE-66. 90 p.

Birch, T. W. 1979. The forest-land owners of Ohio - 1979. USDA For. Serv. Resour. Bull. NE-74. 84 p.

Birch, T. W., and N. P. Kingsley. 1978. The forest-land owners of West Virginia. USDA For. Serv. Resour. Bull. NE-58. 76 p.

Birch, T. W., and D. S. Powell. 1978. The forest-land owners of Kentucky. USDA For. Serv. Resource Bull. NE-57. 101 p.

Burgess, J., and F. Cubbage. 1988. 1988 Timber harvesting equipment costs. For. Eng. 6.9. Univ. of Georgia, School of For. Resources. Athens, GA. 3 p.

Dale, M. E., and R. L. Brisbin. 1985. Butt log quality of trees in Pennsylvania oak stands. USDA For. Serv. Res. Pap. NE-568. 8 p.

Hilt, D. E. 1985. OAKSIM: an individual tree growth and yield simulator for managed even-aged upland oak stands. USDA For. Serv. Res. Pap. NE-562. 21 p.

Koger, J. L. 1981. Transportation methods and costs for sawlogs, pulpwood, and longwood. Tech. Note B46. TVA Div. of Lands and Forests. Norris, TN. 36 p.

LeDoux, C. B. 1987. Estimating yarding costs for the Clearwater cable yarder. USDA For. Serv. Res. Pap. NE-609. 4 p.

LeDoux, C. B. 1986. MANAGE: A computer program to estimate costs and benefits associated with eastern hardwood management. USDA For. Serv. NE-GTR-112. 7 p.

LeDoux, C. B. Unpub. EASTCOST - stump-to-mill timber production cost equations and computer program. Unpub. report on file at USDA For. Serv. Northeast. For. Exp. Sta., 180 Canfield St., Morgantown, WV.

Martin, A. J. 1981. Taper equations for selected Appalachian hardwood species. USDA For. Serv. Res. Pap. NE-490. 22 p.

Ohio Agriculture Statistics Service. 1989. Ohio timber prices, Feb. 1, 1989. Ohio Agric. Stat. Serv., Columbus. 2 p.

Pennsylvania State University. 1988. Pennsylvania timber market report. The Pennsylvania State Univ. School of Forest Resour., Coop. Ext. Serv., University Park. 5 p.

Reisinger, T. W., D. W. Greene, and J. F. McNeel. 1988. Microcomputer-based software for analyzing harvesting systems. South. J. Appl. For. 12(1):37-41.

Risbrudt, C. D., and J. A. Pitcher. 1986. Financial returns from timber stand improvement investments. North. J. Appl. For. 3:52-58.

Schnur, G. L. 1937. Yield, stand, and volume tables for even-aged upland oak forests. USDA Tech. Bull. 560. Washington, DC. 87 p.

Shifley, S. R. 1987. Evaluating management alternations with TWIGS and ERGYS. In: Economics of eastern hardwood management. March 9-11, 1987, University park, PA. The Pennsylvania State Univ., University, Park. P. 168-187.

Solomon, D. S., and R. A. Hosmer. 1987. A growth and yield model (FIBER) for multiple species stands within different forest types. USDA For. Serv. Gen. Tech. Rep. NC-120. p. 217-223.

Stuart, W. B. 1982. Logging cost by diameter class. In: Harvesting small timber: waste not, want not. April 28-30, 1983, Syracuse, NY. For. Prod. Res. Soc., Madison, WI. p. 75-83.

Yaussey, D. A., R. L. Brisbin, and M. J. Humphreys. 1988. Predicting volumes and numbers of logs by grade from hardwood cruise data. USDA For. Serv. Res. Pap. NE-613. 15 p.