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Site Quality in Appalachian Hardwoods: The Biological and Economic Response Under Selection Silviculture

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NORTHEASTERN FOREST EXPERIMENT STATION
FOREST SERVICE, U.S. DEPARTMENT OF AGRICULTURE
6816 MARKET STREET, UPPER DARBY, PA. 19082
F. BRYAN CLARK, STATION DIRECTOR

The Authors

ORRIS D. McCAULEY is a principal economist at the Northeastern Forest Experiment Station's economics research project at Columbus, Ohio. Before joining the Forest Service in 1956 he served in the Army for 8 years in World War II and the Korean conflict and taught high school for 2 years. He worked in the marketing and processing research project of the Central States Forest Experiment Station at Columbus, Ohio, and later at Berea, Kentucky. He received his bachelor's degree in forestry from West Virginia University in 1949, a master's degree in botany from West Virginia University in 1950, and a master's degree in agricultural economics from The Ohio State University in 1960. He also did graduate work at Indiana University and the University of Kentucky.

GEORGE R. TRIMBLE, JR., was timber-management project leader for the Northeastern Forest Experiment Station at the Timber and Watershed Laboratory at Parsons, West Virginia, until his retirement in January 1974. He received his forestry training at the University of Maine. He worked for a number of years in watershed-management research both in West Virginia and New Hampshire and has worked on forest-management problems throughout most of the Northeastern States.

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ABSTRACT

The relative or percentage value response after 12 years of selective cutting practices on low- and high-quality sites in Appalachian hardwoods amounted to a 119-percent increase on the low-quality site and 145 percent on the high-quality site. The absolute value or actual dollar response, on the other hand, showed that the low-quality site increased in value only $76/acre while the high-quality site increased $233/acre; or it took three low-quality site acres to every 1 high-quality site acre to attain equivalent value change. Current trends in species composition indicate that selective cutting practices will change the species composition toward a climax stand favoring shade-tolerant, slower-growing, lower-valued tree species.

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by Orris D. McCauley
and George R. Trimble, Jr.

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THIS IS an evaluation of the individual-tree-selection system of silviculture, based on a study of sites of two qualities in middle-aged Appalachian hardwoods. Our objectives are to compare the early biological trends in species composition, growth rates, timber quality, and reproduction characteristics by sites, and to compare monetary outcomes for the 12-year period of record based on two cuts and two inventories.

STUDY AREAS

The study was made on two areas on the Fernow Experimental Forest near Parsons, West Virginia. One area was a high-quality site (site index 75 for oak) and the other was a lower-quality site (site index 62 for oak) *(Schnur 1937)* (table 1).

The Fernow Forest is a 3,600-acre outdoor laboratory of the Northeastern Forest Experiment Station. Here the virgin forest was cut over in high-grading operations between 1905 and 1910. The stands at the inception of the management study were 50-year-old second growth with a scattering of old-growth holdover trees from the original harvest.

The climate on the Fernow Forest is normally rainy and cool, and winters are cold. Mean annual precipitation is about 58 inches, evenly distributed throughout the year. Mean annual temperature is about 48°F, and the length of the frost-free season is about 4½ months. Soils of these study areas are silt loams derived from sandstone and shale.

Table 1.—Study-area characteristics

Site designation	Oak site index	Area	Soil type	Elevation	Cuts
	Feet	*Acres*		*Feet*	*No.*
High-quality	75	78	Calvin silt loam	2,600	2
Low-quality	62	23	Calvin-Dekalb silt loam	2,500	2

SILVICULTURAL SYSTEM

The system under study is the selection system which, according to Smith (*1962*), "is applied to any silvicultural program aimed at the creation or maintenance of uneven-aged stands; the selection method is employed for the regeneration of such stands." According to FOREST TERMINOLOGY (*Society of American Foresters 1958*) an uneven-aged stand is one "in which there are considerable differences in age of trees and in which three or more age classes are represented." The terms *uneven-aged management* and *all-aged management* are commonly used interchangeably in describing this system of handling forest stands.

Although the selection system is applied in a variety of ways, it is characterized by periodic cutting of individually marked trees throughout a range of diameter classes. Generally, the marking does not extend below the smallest merchantable size class; this size is determined by the market situation in the area. In many hardwood areas, good markets have been limited until recently (and still are in some areas) to sawlog-size stems (trees larger than 11 inches dbh). This study deals with results of applying individual-tree selection to areas where the production of sawtimber was the only concern.

Most selection silviculture has been applied with only vague guidelines: such objectives as cutting a predetermined volume of timber per acre, eliminating the poor growing stock, or removing certain valuable species. However, to provide indefinitely for approximately equal cuts at more or less equal intervals (cutting cycles) and to maintain near-optimum volume growth and quality increment requires better guidelines than these. In particular, more consideration needs to be given to the residual stand density and to the diameter distribution of stems in it.

De Liocourt devised a method that has been used to guide stand structure, and it has been described by Meyer *et al.* (*1952*). A "Q", or proportional relationship between the number of trees in different diameter classes, defines an inverse J-shaped curve (fig. 1, appendix I). For example, using a Q of 1.3 with 2-inch diameter classes means that the residual stand should contain 1.3 times as many trees in each decreasing dbh class; that is, the 16-inch class should have 1.3 times as many trees as the 18-inch class, etc. In actual practice, marking a stand to leave a given Q is usually implemented by combining the stem-size classes into such groups as poles, small sawtimber, and large sawtimber.

Determination of stand-structure guides involves not only picking a suitable diameter-distribution index, but also deciding what basal area and maximum-size tree to leave (table 1a, appendix I).

All these residual-stand parameters — Q, basal area, and maximum-size tree — are easier to apply than it might appear to those unfamiliar with the concept. The reason is that they need be only approximations. The fact that these guidelines can be approximated, however, does not mean that they are unimportant. The practice of the selection system over a long period requires a stand structure that will insure sufficient harvestable trees of the larger dbh classes.

STUDY METHODOLOGY

BIOLOGICAL

The study areas were small watersheds with surveyed boundaries. Site quality was determined from a grid system of plots, using the method of Trimble and Weitzman (*1956*), which employed the site-index curves of Schnur. Silvicultural guidelines were based on local experience and on what information was available (table 2). During the period when management was being begun, the main emphasis was on conditioning these previously unmanaged stands within the framework of the system but without undue concern for close adherence to regulation goals.

The use of a Q of 1.3, rather than the 1.5 to 1.6 ratio found locally in unmanaged stands, provides for more growing stock in the larger tree classes. This favors potentially higher returns to applied forest practices as long as it provides sufficient lower-diameter trees to grow into the next larger class. Our experience to date indicates that it does.

The goals for residual basal area, maximum-size leave tree, and cutting-cycle length (table 2) are based partly on the results of local studies of stand and individual-tree growth rates *(Trimble 1968)*.

To measure growth rates, species composition, and diameter distribution, we made periodic stand inventories; 100 percent for all trees over 5.0 inches dbh and 1 to 5 percent (1/100-acre plots on a grid) for stems 1 to 5 inches dbh. Log grade was estimated in the standing trees on a sampling basis (*Ostrander et al. 1965*). We made two inventories; one at the beginning and one at the end of the study period. The initial inventories for the study areas were completed in early 1958. The initial selection cuts were made during the dormant season of the same year. The second cuts were completed in the spring of 1968. The final inventories were made during the dormant season in 1969-70.

The initial cut in these stands (the first of the two improvement cuts) emphasized the harvesting of overmature timber (old residuals) and poorer individuals of sawtimber-size in the second-growth stand. Culls larger than 11 inches dbh were either girdled or treated with ammate crystals in chopped cups.

In the second cut, we gave more emphasis to the attainment of a balanced stand structure. The few culls that had developed in the 10-year period between cuts were girdled with a power saw by the timber faller.

ECONOMIC

To make an economic evaluation of the biological response, we used a market structure that was realistic for the study area. Because of the dynamic nature of markets, the cost–price framework selected for our analyses may not be that always used by timber buyers in the study area, but it is one that can be

Table 2.—Biological goals of management

Site designation	Q	Number of trees/acre			Residual basal area in trees over 11.0 inches dbh	Maximum size tree dbh	Gross[a] residual volume/acre	Length of cutting cycle
		6-11 inches	12-17 inches	18+ inches				
		No.	*No.*	*No.*	*Sq. ft./acre*	*Inches*	*M bd. ft.*	*Years*
High-quality	1.3	49	22	17	70	32	12.9	10
Low-quality	1.3	52	24	8	40	20	5.5	10[b]

[a] Based on local volume tables made at initiation of stand management. Board-foot measurement is by International ¼-inch kerf rule to an 8-inch top, diameter inside bark.

[b] Indications are that on sites of this quality the cutting cycle should probably be lengthened to about 15 years.

Table 3.—Stumpage prices used for stand economic evaluation [In dollars]

Species group number	Sawtimber species included in group	Per thousand board feet			
		Trees with butt-log grade 1	Trees with butt-log grade 2	Trees with butt-log grade 3	Trees with lower butt-log grades
1	Miscellaneous spp.[a]	$ 6	$ 6	$ 6	$ 1
2	White oak	57	16	1	1
3	Red oak	69	34	12	1
4	Yellow-poplar[b]	58	32	16	1
5	Black cherry	121	75	35	1
6	Sugar maple	87	42	9	1
7	Red maple	72	32	2	1
8	Sweet birch	91	34	1	1
9	Basswood	69	39	17	1
10	White ash	118	56	21	1

[a] Includes hemlock, bigtooth aspen, hickories, American beech, chestnut oak, elms, black gum, butternut, and other species when of merchantable size such as eastern hophornbeam, Fraser magnolia, sassafras, black locust, and sourwood (scientific names are given in appendix IV).

[b] Includes cucumbertree.

described and that provides a basis for evaluation.

The market structure we applied in this study is that used by the USDA Forest Service for stumpage appraisal on the Monongahela National Forest. It involved the use of: (1) butt-log tree grades, (2) stumpage prices by tree grade, and (3) species grouping based on grade and price levels (table 3). The prices used are net sums developed from an analysis of grade-lumber recovery values, minus total lumber-conversion costs.

For low-grade trees, conversion costs can exceed tree value, resulting in negative stumpage values. To avoid negative values in the analysis, all negative stumpage-appraisal prices were assigned positive $1.00-per-thousand-board-foot values. For this reason, all merchantable trees below butt-log grade 3 were arbitrarily grouped and assigned a value of $1.00 per thousand board feet.

The values for analysis and evaluation were derived by applying butt-log grade and price information (table 3) to volume of the original and subsequent inventories and to the volume removed by each harvest.

Costs of 1¢ per diameter inch were used to determine the cost of cull removal. These costs were deducted from the returns as they were incurred.

The per-acre values shown in this report are net summations of periodic inventory value or harvest incomes.

All stumpage prices and costs used in the evaluation were maintained at a constant level to avoid the change in money values due to inflation. Furthermore, implicit in our constant-price assumption is that all products would sell in the market at the quoted prices.

Because the product goal is realistically restricted to the sale and value of sawtimber alone, the stand valuation excludes growing-stock values and investment costs for trees below sawtimber size in the investment analyses. Under this treatment and product goal, growing-stock volume is valued as the trees attain the minimum sawtimber dbh of 11.0 inches.

RESULTS

BIOLOGICAL

To determine the effects of site on stand characteristics, we examined a number of features. We compared species composition of all size components of the stand; we determined stand growth rates in board feet and basal area; we appraised timber quality in terms of log grade, scaling deductions, and cull trees; we surveyed the origin, number, and distribution of reproduction stems, and we looked at stand structure as it was affected by the two cuts.

Species Composition

Both sites contained a large number of different commercial species, and this was true of all the stand segments we looked at: the 1- to 5-inch stems, the 5- to 11-inch stems, and the stems over 11.0 inches dbh — the sawtimber stand (table 4).

We looked primarily for two kinds of relationships in species compositions: relationship to site quality and relationship to cutting practice. (See appendix IV for a list of tree species found in study area.)

In examining the relationship to site, we looked first at the stand over 11.0 inches dbh as it was before initiation of management. We found that, on the high-quality site, 30 percent of the stems were composed of the more desirable commercial intolerants, black cherry and yellow-poplar; but on the low-quality site the stand showed only about 8 percent of these species. The oaks, less demanding in site quality, made up about 23 percent of the overstory on the high-quality site and about 44 percent of the stands on the lower-quality site. Both of these species relationships to site quality are typical.

In examining the advanced reproduction for site-related effects, we found that, after two cuts, sugar maple and beech were most numerous on the good-quality site and beech and red maple on the low-quality site.

To get an indication of the effects of the cutting practice on species composition, we compared the 1- to 5-inch stems of advanced reproduction (tallied at the second inventory) to the 11.0-inch-plus overstory as it was before the first cut. The advanced reproduction came in under a full to partial canopy; the overstory resulted from a commercial clearcut in the virgin forest and from wildfire.

On the high-quality site, black cherry and yellow-poplar made up 30 percent of the overstory stems before the first cut but less than 1 percent of the advanced reproduction. The shade-tolerant sugar maple, beech, and red maple made up 26 percent of the overstory but 87 percent of the advanced reproduction. On the lower-quality site, the oak group made up 44 percent of the overstory but only about 8 percent of the advanced reproduction. Individual-tree-selection cutting is reducing black cherry and yellow-poplar on the high-quality site and reducing oak in the low-quality site. Indications are that, in the future mature stands on the high-quality site, sugar maple and beech will predominate; and on the low-quality site, beech and red maple will make up over half the stems.

Growth

The stands were well stocked at the beginning of management. Basal area in trees over 5.0 inches dbh ranged from 95 to 114 square feet. This is well above the minimum level that Fernow studies have shown to be adequate for maximum growth on these sites (*Trimble 1968*). After the second cut, stocking was still well above the minimum level (table 5).

Computed growth included both accretion

Table 4.—Species composition of merchantable tree stands

[Most numerous commercial species are listed in numerical order and as percentage of total stand]

1- to 5-inch stems				5- to 11-inch stems				Trees over 11 inches			
Before first cut		After second cut		Before first cut		After second cut		Before first cut		After second cut	
					HIGH-QUALITY SITE						
	Percentage		*Percentage*		*Percentage*		*Percentage*		*Percentage*		*Percentage*
Sugar maple	42.7	Sugar maple	42.8	Red oak	14.1	Sugar maple	16.0	Black cherry	17.2	Red oak	24.2
Beech	33.8	Beech	34.2	Sweet birch	12.5	Sweet birch	13.2	Red oak	15.6	Black cherry	16.9
Red maple	10.3	Red maple	9.8	Sugar maple	7.8	Red maple	10.7	Beech	15.4	Yellow-poplar	14.4
Sweet birch	4.6	Basswood	2.4	Red maple	7.7	Red oak	10.0	Yellow-poplar	12.5	Beech	11.3
Red oak	2.6	Fraser magnolia	2.1	Black cherry	7.6	Beech	9.8	Sugar maple	7.4	Sugar maple	5.8
Cucumber	1.0	Sweet birch	1.8	Black locust	7.4	Cucumber	6.0	Chestnut oak	4.7	Chestnut oak	5.0
Hickory	.9	Red oak	1.5	Beech	6.9	Chestnut oak	4.6	Sweet birch	4.7	Sweet birch	4.6
Yellow birch	.7	Black locust	1.2	Chestnut oak	5.6	Black cherry	4.2	Hickory	4.1	Red maple	4.0
Basswood	.7	Black gum	1.2	Yellow-poplar	5.3	Yellow-poplar	3.8	Red maple	2.9	Hickory	2.7
Black gum	.7	Cucumber	.9	Cucumber	5.3	White ash	3.7	Black gum	2.9	White oak	2.2
Hophornbeam	.5	Hickory	.6	White oak	4.9	Black locust	3.2	White oak	2.5	Cucumber	2.1
Miscellaneous	1.5	Miscellaneous	1.5	Miscellaneous	14.9	Miscellaneous	14.8	Miscellaneous	10.1	Miscellaneous	6.8
					LOW-QUALITY SITE						
Beech	34.4	Beech	40.9	Sassafras	21.6	Red maple	16.6	Red oak	22.1	Red oak	32.4
Red maple	20.0	Red maple	19.0	Red oak	13.1	Red oak	14.8	Chestnut oak	19.8	Chestnut oak	21.3
Sugar maple	11.4	Fraser magnolia	8.7	Fraser magnolia	11.1	Fraser magnolia	10.7	Beech	14.8	Red maple	9.2
Red oak	8.0	Sweet birch	6.8	Red maple	11.0	Sassafras	10.3	Black gum	10.0	Beech	7.9
Sweet birch	5.5	Red oak	4.9	Chestnut oak	10.1	Chestnut oak	10.0	Red maple	7.2	Fraser magnolia	5.5
Fraser magnolia	5.1	Black gum	4.8	Sourwood	7.2	Sweet birch	8.3	Yellow-poplar	5.1	Yellow-poplar	4.8
Sassafras	4.4	Sourwood	3.8	Black locust	5.6	Sourwood	7.8	Sweet birch	3.7	Black gum	3.1
Chestnut oak	3.2	Sugar maple	3.1	Sweet birch	5.2	Beech	7.0	Black cherry	3.1	Black cherry	2.5
Hophornbeam	2.5	Chestnut oak	2.0	Beech	4.9	Cucumber	3.9	Fraser magnolia	2.4	Sweet birch	2.4
White oak	2.5	Cucumber	1.6	Cucumber	3.3	Black locust	3.0	White oak	2.2	White oak	2.3
Black gum	1.3	Black locust	1.4	Black cherry	1.4	Sugar maple	1.5	Hickory	2.1	Cucumber	1.9
Miscellaneous	1.7	Miscellaneous	3.0	Miscellaneous	5.5	Miscellaneous	6.1	Miscellaneous	7.5	Miscellaneous	6.7

Table 5.—Periodic annual growth per acre

Site designation	Board-foot growth[1]		Basal area at last inventory		Basal-area growth in trees over 5.0 inches
			In trees over 5.0 inches	In trees over 11.0 inches	
	Bd. ft.	*Pct.*	*Sq. ft.*	*Sq. ft.*	*Sq. ft.*
High-quality	385	3.1	99	71	2.0
Low-quality	249	3.4	89	47	2.3

[1] International ¼-inch kerf rule, to an 8-inch top dib, in trees over 11.0 dbh.

Table 6.—Per-acre volumes, merchantable and cull

Site designation	Before first cut				After recruise 12 years later			
	Merchantable volume	Cull-tree volume	Total volume	In cull trees	Merchantable volume	Cull-tree volume	Total volume	In cull trees
	Bd. ft.	*Bd. ft.*	*Bd. ft.*	*Pct.*	*Bd. ft.*	*Bd. ft.*	*Bd. ft.*	*Pct.*
High-quality	11,179	1,390	12,569	11.06	11,230	24	11,254	0.21
Low-quality	6,115	1,233	7,348	16.78	5,624	17	5,641	.30

(growth on residual trees above the minimum sawtimber diameter) and ingrowth, but excluded mortality. Board-foot and basal-area growth computations included volumes cut as well as growth on standing trees.

During the study period, annual growth on the high-quality site was 385 board feet per acre and on the lower-quality site 249 board feet (table 5). With a site difference between sites of about 13 feet of site index, the average annual growth advantage of the better site was about 10 board feet for each foot of site index.

Annual basal-area growth in trees over 5.0 inches dbh ranged from 2.0 to 2.3 square feet; and if there was a relationship to site quality, it was masked by the effects of other stand variables.

Timber Quality

Timber quality of sawlog-size trees was measured by: (1) the volume of the cull trees in the stand, (2) defective material in merchantable trees, and (3) the grade of logs in merchantable trees.

Total inventories gave us the volume in cull trees; scaling records provided an estimate of volume in defects; and sample-tree grading during the inventories yielded an estimate of log grade in the sawtimber stand.

Through the girdling of cull trees, the percentage of stand volume in these trees was reduced from 11.06 to 0.21 in the high-quality site area; from 16.78 to 0.30 percent for the low-quality site area (table 6). We see no relationship in these figures to site quality. At each harvest, all cull trees over 11.0 inches dbh in the stand were killed. (A cull tree was defined as a tree over 11.0 inches dbh that does not contain at least one 16-foot log having 50 percent or more of merchantable volume.) The drastic reduction in cull-tree volume was in accord with results from similar practices on other areas (*Trimble 1965, Trimble 1970*).

Scaling deductions dropped sharply from the first to the second cut, as follows: high-quality site from 9.3 to 5.2 percent, low-quality site from 17.0 to 6.6. These deductions included cull logs in merchantable trees that were not butted off before skidding; they also included crook, sweep, shake, and rot in merchantable logs.

Table 7.—Percentage of stand sawlog volume by butt-log grade

Butt-log grade	Before first cut	In first cut	In second cut	After second cut
HIGH-QUALITY SITE				
1	11.9	1.9	17.4	30.0
2	11.3	4.3	20.3	23.0
3	42.1	31.3	44.4	36.0
4 and 5	32.8	60.7	12.9	10.1
6	1.9	1.8	5.0	.9
LOW-QUALITY SITE				
1	14.2	6.3	25.1	29.1
2	16.1	15.2	15.0	24.6
3	32.3	16.3	34.1	37.9
4 and 5	33.9	55.6	20.3	7.9
6	3.5	6.6	5.5	.5

Factory-log grades 1 and 2 make up the bulk of the money value in a stand. The silviculture practiced over the study period has raised the percentages of sawtimber volume in these two grades (table 7). For the high-quality site the increase was from 23.2 percent to 53.0; for the low-quality site the increase was from 30.3 to 53.7. The improvement in grade was also strongly reflected in the large percentage increase in the number of trees moving from log grade 2 to log grade 1 between the first and second cuts.

Reproduction Characteristics

We used the 1- to 5-inch stems, or advanced reproduction, to indicate the trend of stand regeneration resulting from a single cutting practice (individual tree selection cutting) applied on sites of contrasting quality.

The number of advanced reproduction stems per acre after the second cut was 323 for the high-quality site and 492 for the low-quality site. Eleven percent of the stems on the high-quality site and over 16 percent on the low-quality site were sprouts (table 8).

The percentage of good stems (potentially good-quality sawtimber trees) by areas ranged from 74 for the low-quality site to 89 for the high-quality site (table 8).

In all stands, the advanced reproduction stems of commercial species were well dis-

Table 8.—Number, distribution, origin and quality of 1-to 5-inch stems of commercial species after two cuts

Site designation	Stems per acre	Sprouts	Good-quality stems	Sampled 1/100-acre plots stocked with commercial species
	No.	*Pct.*	*Pct.*	*Pct.*
High-quality	323	11.0	89.3	87.5
Low-quality	492	16.8	73.9	94.7

tributed. On the high-quality site, 88 percent of the sampled 1/100-acre plots contained stems, as did 95 percent of the plots on the low-quality site.

Stand Structure

Average Q's and numbers of trees by diameter groups were compared for three time periods (table 9); (1) before the first cut, (2) at the second inventory, and (3) when management goals are attained (a situation anticipated at some time in the future).

The number of trees in the 5- to 11-inch dbh group is not controlled, because no cutting is done below sawlog size — 11.0 inches. As is evident (table 9), the number of stems in this size group is far more than enough to supply the stems needed in the 11- to 17-inch class (small sawtimber). In other words, there is no indication that we are going to run out of trees to cut. To the contrary, the excessive number of poles indicates that in the absence of cutting in the stand below sawtimber size, we are probably providing unfavorable conditions (too much competition) for the best growth of sawtimber-size trees. The net result will be a less valuable periodic harvest; a higher proportion of the harvest will be ingrowth (12- and 14-inch trees) than would be the case if we were also periodically harvesting trees from the 5- to 11-inch stand.

During the period of management, size of sawtimber trees has changed little, as indicated by the average dbh of merchantable trees over 11.0 inches (table 10).

Table 10.—Average dbh of sawtimber trees, in inches

Site designation	Before first cut	After second cut	Goal of management for residual stand
High-quality	15.6	16.0	17.4
Low-quality	15.1	15.0	15.0

ECONOMIC

Economic evaluations can be developed and applied to a forest practice by using the biological response by site quality. The primary emphasis here is to demonstrate valuation techniques and the application of various investment measures that can serve as the basis for decision-making.

In arriving at a decision to invest in a forest practice, the investor usually reviews all the expected returns and risks associated with the investment. He has the opportunity, first, to invest his savings in a savings bank — with little if any risk. Or he can use it for other investments and earn greater or smaller returns, usually with more risk of loss.

This opportunity to invest in a savings account or some alternative other than timber should logically be included as a cost of the timber investment. If the market rate of interest is 5 percent, then the investor would

Table 9.—Stand diameter distribution per acre

	Q			Number of trees by diameter groups (inches)								
Site designation	Before first cut	At second inventory	Management goal	Before first cut			At second inventory			Management goal for residual stems		
				5-11	11-17	17+	5-11	11-17	17+	5-11	11-17	17+
High-quality	1.8	1.6	1.3	98	38	14	87	32	16	49	22	17
Low-quality	2.1	1.7	1.3	146	29	9	135	28	9	52	24	8

have $105 at the end of the first year for every $100 invested. And this amount, $105, is compounded, not treated as an investment at simple interest. By investing in his timber stand, the forest manager has foregone the $5 interest he could have earned in his savings bank. Thus, in long-term investment analysis, an appropriate compound or discount rate should be used in evaluating an investment rather than a simple interest rate.

Stand Valuation

To develop the economic measures, we have assumed certain measurement criteria as constant for the 12-year study period. In addition to constant prices and dollar values, we have assumed equal borrowing and lending rates — which are seldom the same in the money markets. Furthermore, the decision about an investment depends on all costs. We have assumed in our analysis that the original sum invested in land was at no cost. Money to invest is assumed to be derived from savings, or reserve funds, or borrowed from a lending agency at the market rate of interest.

Using the cost–price structure referred to earlier, we computed values for the timber inventory before the first cut, the inventory after the second cut, and for the volume removed during each cut.

Expressed in terms of average timber value per acre, the low-quality site increased from $64/acre in 1958 to $140/acre in 1970, an increase of $76/acre. During the same period, the high-quality site's timber value increased from $161/acre to $394/acre, an increase of $233/acre. These figures do not include the value of timber cut.

Another way of showing the improvement in stand value was to express the percentage of stand sawlog value in the different log grades (table 11). The results show that stand value in log grades 1 and 2 has increased from 61 to 86 percent on the high-quality site and from 68 to 86 percent on the lower-quality site. More important than the increase in stand value in log grades 1 and 2 was the reduction in percentage of total value found in the low-quality grades. After the second cut, both stands had less than 15 percent of the total volume in log grade 3 and below. This means that more of the volume growth is on high-quality stems, thus increasing the overall value of the stands.

Table 11.—Percent of stand sawlog value, by log grade and site

Log grade	Before first cut	In first cut	In second cut	After second cut
	HIGH-QUALITY SITE			
1	41	25	55	63
2	20	15	24	23
3	36	50	21	14
Other	3	10	+	+
	LOW-QUALITY SITE			
1	50	51	70	62
2	18	10	16	24
3	28	31	12	14
Other	4	8	2	+

Caution must be exercised in interpreting the increase in value on the two sites. Although the relative increases are not much different — 119 percent for the low-quality site and 145 percent for the high-quality site — the absolute change in the value is much greater for the high-quality site — $233 compared to $76. This means that it takes three low-quality site acres of timber to each high-quality site acre to produce timber of equivalent value. Basically the difference resulted from the high-quality site having better species (in respect to inherent value and grade improvement) and higher growth rates.

Stand Investment

Internal Rate of Return

Internal rate of return (IRR) provides the forest manager or decision-maker with a criterion for measuring how well an investment has performed or is expected to perform. The internal rate of return is that discount rate that will shrink expected or earned incomes from an investment so that it equals the initial cost of the investment. For example, we calculated the internal rate of return by slightly modifying the discount formula:

$$V_o = \frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \ldots \frac{R_n}{(1+i)^n}$$

In the equation, V_o is the beginning value of the investment in timber, or in other situations, the cost of applying a forest practice; R_1, R_2 . . . R_n are expected or earned net incomes from the investment, the subscript representing the year in which a specific income occurred; *i* is the discount rate that shrinks the income stream (R's) so that the sum of discounted incomes is equal to V_o, the investment.

In application, since *i* is unknown and appears in several terms, a trial-and-error process is usually used to find the *i* that satisfies the equation. That is, a trial *i* is used to discount each R to the beginning of the investment period. If the sum of discounted R's is larger than V_o, select a larger *i* and repeat. Resolve until the sum of discounted incomes is approximately equal to V_o.

Normally, the internal rate of return is used to find the rate of return from an expected or estimated future income stream resulting from an investment, but it can be used as well to discount incomes after they have been earned, as we have applied it in our site evaluation. In table 12 we have listed the application of the internal rate of return to our study.

For each site we show the discount period or the year the income was earned, n, in column 1; original stand value or investment, V_o, in column 2; the net income stream, R, in column 3; and the factor $(1+i)^n$ in column 4.

Using the trial-and-error method and substituting these values in the IRR equation for our site-quality classes, we find that a discount rate of 9.7 percent most nearly equates the flow of net incomes from the high-quality site with the initial investment of $161.46/acre. Likewise, a 10.6-percent discount rate most nearly equates the low-quality site income stream with the initial investment of $63.68/acre. See appendix II for the trial-and-error calculations.

These are relatively high returns for an investment in timber on either high- or low-quality sites, the low-quality site exceeding that of the high-quality site at least for the 12-year period. But we must recognize exactly what we have measured with the IRR, how to apply and interpret the investment measurement, and the conditions and constraints that might affect the size of the IRR.

First, when using the IRR, we are looking at an investment within the business rather than of the total business investment and the total flow of expected net income (returns minus costs), which involves outside factors such as the cost of borrowing funds. Often it

Table 12.—Values used to compute the Internal Rate of Return for the high- and low-quality site investment

Equation symbol								
n (1)	V_o (2)		R (3)		$(1+i)^n$ (4)			
Discount period or year income earned	Beginning investment/acre		Net income/acre		Discount factor at given interest rate[a]			
	Low site	High site	Low site	High site	9.7%	9.8%	10.5%	10.6%
0	$63.68	$161.46	——	——	——	——	——	——
1	——	——	$14.65	$13.72	1.097	1.098	1.105	1.106
2	——	——	——	——	1.203	1.206	1.221	1.223
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
.	——	——	——	——	——	——	——	——
10	——	——	23.24	50.32	2.524	2.547	2.714	2.739
12	——	——	140.28	394.13	3.037	3.071	3.314	3.350

[a] From Marty and Neebe 1966.

is difficult to separate the flow of income attributable to a forest-practice investment from the income stream that would have occurred if the investment had not been made.

Second, in arriving at our IRR's, we have held stumpage prices at a constant level. This is a bit unrealistic, but in practice we do this to avoid value change caused by changing prices. The value change we want to measure is the one expressed by growth and quality development in the stand. Ordinarily, over short periods of time we would not expect stumpage prices to change; but when they do, the forest manager must recognize and make adjustments for all changes that increase or decrease the flow of income from the investment.

A third factor that must be considered when interpreting the IRR for an investment is an adjustment for risk and uncertainty for losses due to fire, weather damage, and insect attacks. The probability of such losses is always present, and it fluctuates over time and with location.

A fourth condition to be reckoned with in applying the IRR is that we are measuring the relative or percentage change in value. Thus in our analysis, we show the low-quality site having a greater relative value change over the study period, 10.6 percent versus 9.8 percent for the high-quality site. In absolute or actual-dollar value, the low-quality site increased from \$64/acre to \$140/acre for a net increase of \$76/acre while the high-quality site increased from \$161/acre to \$394 /acre or \$233/acre.

The stand age and stage of development of the stand also influence the outcome and size of the IRR. Certainly the flow of income from a young developing stand differs from that of a mature stand. Likewise, the income flow from an older stand producing salable sawtimber is lumpy. We would expect the IRR of a timber investment in sawtimber to be at its maximum during the period when the stand is making its greatest growth and quality development. Similarly, where improvement costs are low, as we have demonstrated in our site-quality studies, the value change, expressed by placing volume growth on higher valued stems, will result in a more favorable IRR.

Net Future Value

A forest investor or manager may express an income goal that must be satisfied before he decides to invest. Specifically, his decision to invest may be based on a rate of interest that will satisfy an expected future value for the investment. Net future value (NFV) is a concept that can be applied in such a case to provide the manager with an estimate of the outcome of his investment.

To find the net future value we use the compounding process wherein:

$$V_n = V_o\ (1+i)^n$$

When: V_n = The net future value of an investment at the end of investment period.

V_o = The value of the investment at the beginning of the investment period.

n = Length of the investment period, in years.

i = The compounding rate; the rate of interest the manager desires on the investment.

We illustrate in simple form how the net future value of an investment is applied, using our own site-quality values for the low-quality site and assuming no income from cutting. As forest managers, we specify that our investment in the forest must earn at the rate of 5 percent or better during 12 years. What future timber value/acre at the end of 12 years is necessary to earn this rate of interest on the investment? Using the net-future-value equation, we find:

V_o = \$63.68 = the original investment in the timber stand.

n = 12 years, the number of years the \$63.68 has been invested in the timber stand.

$(1+i)^{12}$ = 1.79586 = factor for 5-percent compounded interest for 12 years, found in compound interest tables.

Then, substituting the low-site values in the net-future-value equation, $V_n = V_o\ (1+i)^n$, we find:

$$V_n = \$63.68\ (1.79586) = \$114.36$$

In table 13, we show the performance of timber sites at varying rates of interest. (We have rounded our values in the table to the nearest whole number.) Values shown in column 3 were calculated in the same manner as above, using the net-future-value equation and compounding the $64 investment in column 2 at the interest rates shown in column 1. In column 4, we show the net value difference between what the manager or owner specified as his goal in the investment compared to the performance of our site-quality stands for the 12-year period.

For example, if the manager or owner would accept breaking even (zero interest) in making an investment ($64/acre) in our low-quality site stand, at the end of 12 years he would have received his $64 back plus a bonus of $76. The actual low-quality site value at the end of 12 years was equal to $140/acre; then by subtracting the value in column 3 from $140, we arrive at the value shown as surplus or loss in column 4.

When the specified interest rate is equal to 6.8 percent, the net future value or required value of the original investment ($64) after 12 years is equal to $140/acre. At the end of the 12-year period, the low-quality site stand was valued at $140/acre. We have equated the original investment at an interest rate that equals the actual stand value after 12 years. Stated in another way: when the value of the stand after 12 years is equal to $140/acre, the performance of the stand is equal to an investment of $64/acre for 12 years at 6.8 percent compound interest. (In the IRR solution, the rate earned was 10.6 percent when revenues from timber cut were included.) Table 13 shows that, at interest rates greater than 6.8 percent, the required stand value (the net future value of an investment of $64/acre for 12 years) would exceed the actual performance of the low-quality site.

Our illustration above shows the application of the net-future-value concept in an elementary form to our site-quality evalua-

Table 13.—Stand performance based on net future value and owner's desired rate of interest on investment

[In dollars]

Rate of interest (percent)	Beginning or initial investment/acre, 1958	Required value in 1970/acre for stand to earn indicated interest rate (net future value)	12-year results: surplus/acre[a]
		LOW-QUALITY SITE	
0	$64	$64	$76
2	64	81	59
3	64	91	49
4	64	102	38
5	64	114	26
6	64	128	12
6.8	64	140	0
8	64	160	–20
10	64	200	–60
		HIGH-QUALITY SITE	
0	161	161	233
2	161	205	189
3	161	230	164
4	161	258	136
5	161	290	104
6	161	325	69
7.7	161	393	1
8	161	407	–13
10	161	507	–113

[a] These figures are the difference between the actual stand values in 1970 ($140 for low-quality site stand, $394 for high-quality site stand) and the required stand value in 1970.

tion as a measure of the effectiveness of our initial investment. In a forest business, the total net cash flow or net income stream from the investment must be accounted for to show the true performance and effectiveness of the investment. Column 4 of table 13 shows only the difference in value of our initial investment at a desired rate of interest and the end value after 12 years. The net income from the harvest or improvement cuts made since the initial investment is a part of the total income stream from the initial investment, and logically it should be reinvested. We can calculate the true net future value of the initial investment by slightly modifying the basic net-future-value equation to include the income from cuts as well as ending-inventory value. The equation modification and computations for inclusion of total income flow are shown in appendix III.

Other Investment Considerations

Up to this point, in our economic analyses we have considered as a cost only the initial value of the timber. To provide additional realism in evaluation, we now include the costs of land, managerial costs, and tax costs. As will be seen, the addition of these costs does not change the relative ranking of the high- and low-quality sites. However, addition of these costs to the investment does illustrate how they change the investment opportunity and outcome.

This evaluation is made on the assumption that timber alone must carry the total investment cost. Under this assumption, we ignore other income possibilities. Some of these, such as increases in land values, may require no added investment, while others — such as leasing hunting rights — may require additional labor and managerial costs.

In our analyses, we have combined managerial and tax costs under the heading of *annual management-tax costs* for ease in computing and presenting the tables. As investment costs, they are subject to and accounted for by the same investment equation in the analyses.

Timber and land investment. — Our first example shows the possible investment outcome on high-quality and low-quality sites where the forest owner considers only the land and timber-investment costs (table 14). Using our 12-year record of the applied silviculture, we show under varying land costs and interest rates how the investment opportunity changes.

To calculate the values shown in table 14 we apply the previously explained net-future-value equation, $V_n = V_o\ (1+i)^n$. Since both land and timber costs are part of the initial investment, we use the sum of these two values. For example, to find the stand value/acre necessary to earn 5 percent on the investment after 12 years when land costs are \$10/acre, we find: V_o=\$63.68/acre (timber cost) + \$10/acre (land cost) = \$73.68/acre (total cost); $(1+i)^n = (1+.05)^{12} = 1.79586$; then, V_n=\$73.68/acre (1.79586) = \$132.32/acre. The other stand values shown in table 14 were computed in the same manner at various interest rates and land values. The investment opportunity changes with investment costs.

To further explain the use of table 14, we use the low-quality site investment and an investor's desire for a 5-percent rate of interest on his land and timber investment. He could be successful only if he paid \$14/acre or less for his land and a sawtimber inventory valued at \$64/acre or a total investment of not more than \$78/acre (V_n=\$78 (1.79586) = \$140.08).

If the investor paid \$79/acre, our data show, the stand would have to reach a value of \$142/acre (V_n=\$79 (1.79586) = \$141.87) in 1970 to earn 5 percent in the investment, when in fact it was valued only at \$140/acre. Similarly, the high-quality site would earn the forest owner more than 6 percent on an investment if the land cost less than \$35/acre.

The values under the heavy lines in table 14 all exceed the average per-acre value attained during the 12-year study period; these values would be necessary to earn the indicated percentage return.

Timber and management-tax investment.— For situations where a forest owner does not consider land cost as a part of his investment, we show how taxes and management costs might influence the timber investment in forest practices (table 15).

Table 14.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated land and timber investment

[In dollars]

Investment per acre			Stand value/acre necessary to earn the indicated interest rate after 12 years[a]					
Initial land cost	Initial timber value	12-year total	2%	3%	4%	5%	6%	7%
		LOW-QUALITY SITE						
$10	$64	$74	$93	$105	$118	$132	$148	$166
15	64	79	100	112	126	141	158	177
25	64	84	112	126	142	159	178	200
35	64	99	125	141	158	177	199	222
50	64	114	144	162	182	204	229	256
75	64	139	176	198	222	249	279	312
100	64	164	208	233	262	294	329	369
125	64	189	239	269	302	339	380	425
150	64	214	271	305	342	384	430	481
		HIGH-QUALITY SITE						
10	161	171	217	244	275	308	345	386
15	161	176	224	252	283	317	355	397
25	161	186	236	266	299	335	375	420
35	161	196	249	280	315	353	395	442
50	161	211	268	301	339	380	425	476
75	161	236	300	337	379	425	476	533
100	161	261	332	373	419	470	526	588
125	161	286	363	408	459	514	576	645
150	161	311	395	444	499	559	627	701

[a] Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was $140 for low-quality site stand, $394 for high-quality site stand.

Table 15.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated management-tax and timber-investment costs

[In dollars]

Investment per acre			Stand value/acre necessary to earn the indicated interest rate after 12 years[a]					
Annual management-tax cost	Initial timber value	12-year[b] total	2%	3%	4%	5%	6%	7%
		LOW-QUALITY SITE						
$0.50	$64	$70	$87	$98	$109	$122	$136	$152
1.00	64	76	94	105	117	130	145	161
1.50	64	82	101	112	124	138	153	170
2.00	64	88	108	119	132	146	162	179
2.50	64	94	114	126	140	154	170	188
3.00	64	100	121	133	147	162	179	197
3.50	64	106	128	140	155	170	187	206
4.00	64	112	134	148	162	178	196	215
4.50	64	118	141	155	170	186	204	224
		HIGH-QUALITY SITE						
0.50	161	167	211	237	266	298	333	373
1.00	161	173	218	244	274	306	342	382
1.50	161	179	225	251	281	313	350	390
2.00	161	185	232	259	289	322	359	399
2.50	161	191	238	266	296	329	367	408
3.00	161	197	245	273	304	338	375	417
3.50	161	203	252	280	311	346	384	426
4.00	161	209	258	287	319	354	392	435
4.50	161	215	265	294	326	362	401	444

[a] Includes initial timber investment plus annual costs carried at interest to end of the period.

[b] Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was $140 for low-quality site stand, $394 for high-quality site stand.

For this kind of investment, where there is an annual increase in the amount of invested capital of a portion of the total investment such as the management-tax increment, we must use two equations to find net future value of the total investment. Again we use the net-future-value equation $V_n = V_o (1+i)^n$ for the timber cost portion of the investment. For the management-tax cost, we use the terminable series equation,

$$V_n = \frac{V_o (1+i-1)^n}{i} \text{or total NFV} = V_n =$$

$$Vo_1 (1+i)^n + Vo_2 \frac{(1+i-1)^n}{i}$$

when:

$V_{o\,1}$—The timber investment.

$V_{o\,2}$=The annually recurring management-tax cost.

In applying the equation to show how the values in table 15 are computed, we use the low-site annual management-tax cost of \$1.50 /acre found in column 1, the timber-investment cost of \$64/acre found in column 2, and an interest rate of 5 percent found in column 7. Substituting in the total net-future-value equation, we find:

$$\begin{aligned}
\text{Total NFV} &= \$63.68\ (1+.05)^{12} + \frac{\$1.50\ (1.05-1)^{12}}{.05} \\
&= \$63.68\ (1.79586) + \frac{\$1.50\ (.79586)}{.05} \\
&= \$114.60 + \$23.88 \\
&= \underline{\$138.48}
\end{aligned}$$

Using the results of our analyses for the 12-year study period and the equations shown above, we show the investment outcome at varying annual management-tax costs for the two sites (table 15). If the management-tax costs were \$1.50/acre on the low-quality site, we could attain a 5-percent return; on the

Table 16.—Investment in stand: possible returns after 12 years of uneven-aged cutting at indicated management-tax, land, and timber-investment costs

[In dollars]

Investment per acre				Stand value/acre necessary to earn indicated interest rate after 12 years[a]					
Annual management-tax cost	Initial land cost	Initial timber value	12-year[b] total	2%	3%	4%	5%	6%	7%
			LOW-QUALITY SITE						
\$0.50	\$10	\$64	\$80	\$100	\$112	\$125	\$140	\$157	\$175
1.00	15	64	91	113	126	141	157	175	195
1.50	25	64	107	133	148	165	183	204	227
2.00	35	64	123	152	169	188	209	232	258
2.50	50	64	144	178	198	220	244	271	301
3.00	75	64	175	216	240	267	297	330	366
3.50	100	64	206	255	283	315	350	388	431
4.00	125	64	237	293	325	362	403	447	497
4.50	150	64	268	331	368	410	455	506	562
			HIGH-QUALITY SITE						
.50	10	161	177	224	252	282	316	353	395
1.00	15	161	188	237	266	298	333	372	415
1.50	25	161	204	257	287	321	359	400	447
2.00	35	161	220	276	308	345	385	429	478
2.50	50	161	241	302	337	376	420	468	521
3.00	75	161	272	340	380	424	472	526	586
3.50	100	161	303	379	422	471	525	585	651
4.00	125	161	334	417	465	519	578	644	717
4.50	150	161	365	455	507	566	631	703	782

[a] Includes initial land and timber investment plus annual costs carried at interest to the end of period.

[b] Values to the right of the heavy lines and the indicated interest rates are unattainable because the maximum value/acre generated after 12 years was \$140 for low-quality site stand, \$394 for high-quality site stand.

high-quality site at the same management tax rate, a return greater than 7 percent would be possible.

Timber, management-tax, and land investment. — The opportunity for investment in forest land is less attractive when all costs are chargeable to the productivity of the timber stand. For such cases we have computed the timber-investment outcome for our study sites under varying land and management-tax costs (table 16).

To calculate the values shown in table 16 for the various costs and interest rates, we use the NFV equations as explained in the two previous situations. As an example: to find the stand value/acre on the high-quality site necessary to earn 5 percent when the annual management-tax costs are \$2/acre, land costs \$35/acre, and the timber investment of \$161/acre is compounded for 12 years, we used the two forms of the NFV equation. Summarizing the compounded values in the following equation we find:

$$\text{Total NFV} = \frac{\text{Timber}}{V_o\,(1+i)^n} + \frac{\text{Land}}{V_o\,(1+i)^n} + \frac{\text{Management–Tax}}{\dfrac{V_o\,(1+i–1)^n}{i}}$$

$$= \$161\ (1.79586) + \$35\ (1.79586) + \frac{\$2\ (.79586)}{.05}$$

$$= \$289.95 + \$62.86 + \$31.84$$

$$= \underline{\$384.65}$$

Other total NFV values (table 16) for the various interest rates were computed in a similar manner by substituting the appropriate values in the timber, land, and management-tax equations and finding their sum.

The computations show that it would be possible to earn over 6 percent compounded rate of interest on the high-quality site if annual management-tax costs were in the range of \$1.00/acre and land costs around \$15/acre. Under similar land and annual management-tax costs, we could expect the investment to earn around 3 percent on the low-quality site. Here again, the spread in percentage earnings between sites is a bit unrealistic because it is unlikely that land and tax costs would be the same for high-quality and low-quality sites.

SUMMARY AND DISCUSSION

The study reported here dealt with the results of applying selection silviculture to hardwood stands growing on two areas of different site quality — a high-quality site and a low-quality site. Thus the primary purpose of the study was to record and compare the biological responses and their economic significance attributable to site differences.

The results are strictly applicable only to the case studies described and should be applied with caution to stands, sites, cutting methods, and time periods that differ from those described.

The effects of site differences on biological response were expressed most clearly in species composition and in growth-rate differences. Sugar maple and beech were the two species most favored by selection silviculture on the high-quality site and beech and red maple were favored on the low-quality site. This is in contrast to clearcutting, which favors yellow-poplar and black cherry on high-quality sites and oaks on low-quality sites. Stand board-foot volume increased faster on the better site.

In summation of the biological responses; the results to date indicate that on both sites the imposition of selection cutting as practiced on the study areas will: (1) change the species composition toward a climax stand favoring shade-tolerant slower-growing trees, (2) drastically reduce the proportion of sawtimber in defective and low-grade wood, and (3) provide for adequate stand regeneration. The trends will be the same on both high- and low-quality sites.

In evaluating the economics of selection silviculture on high- and low-quality site sawtimber stands, we are concerned only with those biological responses that influence sawtimber log values. As expected, the responses that are significant biologically are also significant in determining stand values and value differences between sites. These responses are: (1) the trend in quality development, and (2) the trends in species composition.

As shown in the results, favorable quality development did occur on both sites during the study period. This was expressed by (1) an increase of 18 to 25 percent in value due to the proportion of volume in log grades 1 and 2, and (2) a corresponding reduction in value due to reduction of volume in log grade 3 and lower quality classes.

Trends in species development on the two sites have both short-run and long-run significance in stand valuation based on present market preference and stumpage prices. In the short run, the practice of selective cutting on both sites has favored the development of the more desirable high-value species in the overstory.

In the immediate future, we would expect the stand values to continue increasing. However, the biological trends discussed above in species composition perpetuated by selection silviculture will encourage the development of less-preferred, lower-valued sawtimber tree species. This means that in the long run, if current market preference and relative stumpage prices prevail, the more valuable cherry, red oak, and yellow-poplar will be removed as it matures and will be replaced by such less-desirable species as beech, maple, and sweet birch now developing in the understory.

Further economic implications are evident from projecting current trends in stand composition, land values, and other factors as they affect timber values.

- In the long run, as stand-value development stabilizes and as timber values decrease because of the increasing predominance of lower-valued species, the timber investment will be unable to carry the land costs as well as it does at present.

- In the present land market, site quality does not greatly influence the cost of timberland. Many times, land with a high proportion of high-quality site will be marketed at the same price as less productive lower-site timberland. Other factors such as taxes, access, recreation potential, grazing potential, minerals, and location with respect to population centers have greater influence on timberland prices than timber site quality.

- The fact that these factors do have a significant influence on timberland values is important in making decisions on investments in growing timber. When and where the importance of these factors as an investment is increasing, the potential to invest in growing timber at a profit becomes less attractive in the long run and may be submarginal to other alternatives.

- Where a timberland owner has the option to invest in developing low- or high-quality-site timber stands, our results indicate that, per dollar invested, the high-quality-site — because of its faster growth and quality development — will produce timber values on 1 acre equivalent to 3 acres of low-quality-site timber. This ratio of 3:1 would hold true only when the cost of taxes and other costs remain equal.

- For the investor who seeks to buy timberland for the purpose of growing timber, the other-than-timber values play a major role in expected returns. As indicated above, site quality will not influence investment costs and expected returns as much as other timber-related investments. The potential investor must seek timberland where outside factors will not significantly influence the timber investment or where the influence of these factors can be minimized. The probability, that in the future, land can be purchased for the production of timber without the value influence of outside factors is small.

All-important in evaluating the effects of site quality on stand valuation is sound interpretation of the results of percentage and actual dollar value change. For the many economic measures used, we find similar percentage value changes over the period of study on both high- and low-quality sites. Thus, based on percentage value changes, we might erroneously conclude that investments in high- and low-quality sites produce similar economic gains. But, when we measure the value response in actual dollar change, we find the high-quality site increased $233/acre over the study period while the low-quality site increased $76/acre. Obviously, the value of volume and quality development on the better site is superior to that found on the low-quality site.

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APPENDIX I

Table 1a.—Example of using "Q" to determine the distribution of trees by diameter class when the maximum diameter, desired basal area, and Q are given

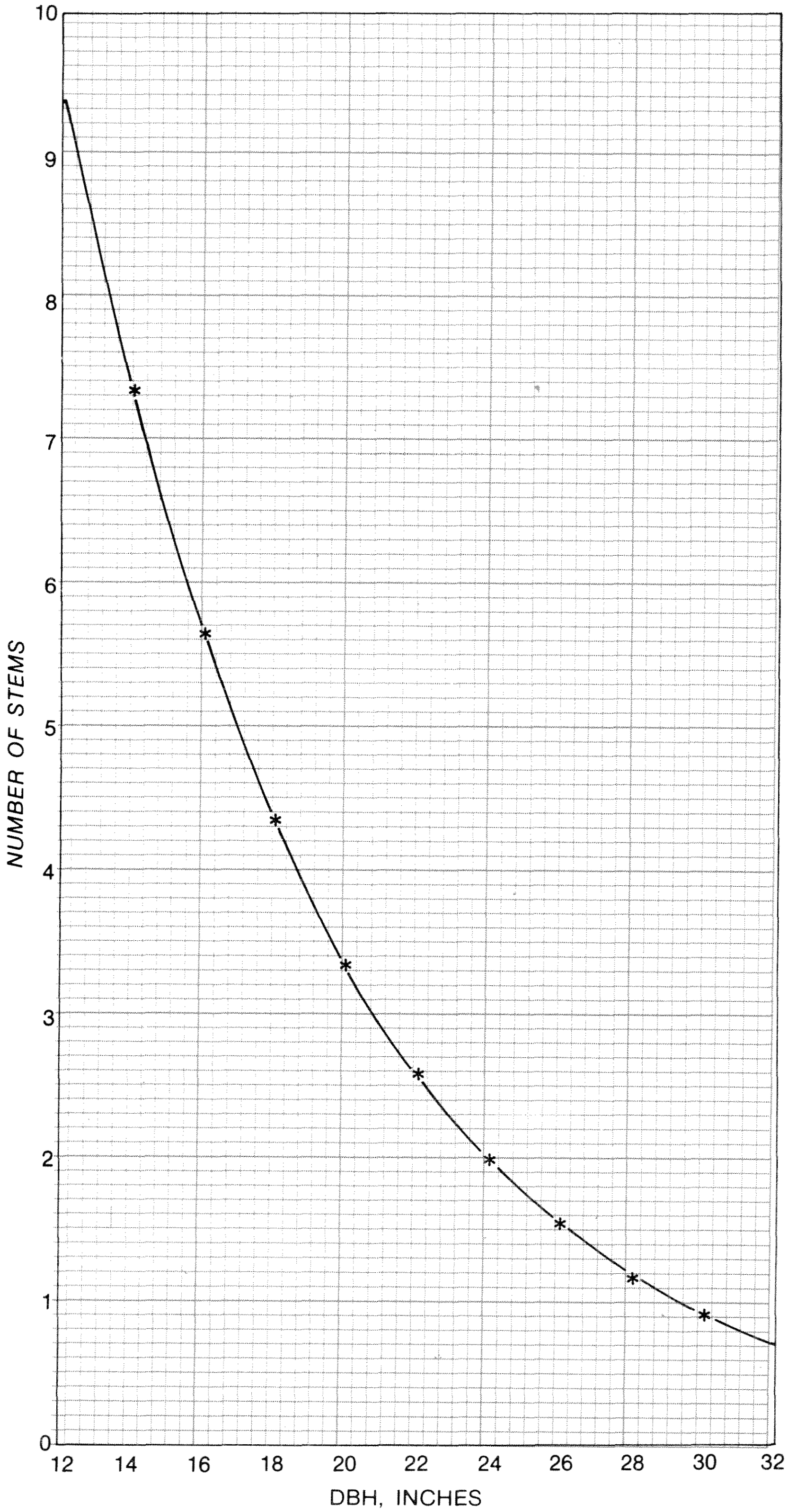
[Given: Q = 1.3; maximum dbh = 32 inches; basal area = 70 square feet]

Dbh class (inches)	Computations for Q distribution				
	Trees	Basal area per tree	Basal-area distribution	Adjusted number of trees	Basal area check
(1)	(2)	(3)	(4)	(5)	(6)
	No.	*Sq. ft.*	*Sq. ft.*	*No.*	*Sq. ft.*
12	13.82	0.785	10.85	9.53	7.48
14	10.63	1.069	11.36	7.33	7.84
16	8.18	1.396	11.42	5.64	7.87
18	6.29	1.767	11.11	4.34	7.67
20	4.84	2.182	10.56	3.34	7.29
22	3.72	2.640	9.82	2.57	6.78
24	2.86	3.142	8.99	1.97	6.19
26	2.20	3.687	8.11	1.52	5.60
28	1.69	4.276	7.23	1.17	5.00
30	1.30	4.909	6.38	0.90	4.42
32	1.00	5.585	5.59	0.69	3.85
Total	—	—	101.42	39.00	69.99

PROCEDURE FOR FINDING ADJUSTED NUMBER OF TREES

1. Set maximum dbh tree equal to 1.00 (32-inch dbh class). Multiply the given Q (1.3) by each preceding Q distribution factor to find number of trees for dbh class, e.g.:
   30-inch dbh class = 1.3x1.00 = 1.30
   28-inch dbh class = 1.3x1.30 = 1.69
   Record in column 2.
2. Find basal area per tree from table of area of circles. Record in column 3.
3. Multiply column 2 by column 3 to find basal-area distribution for each dbh class. Enter product in column 4; for example: 12-inch class = 13.82x.785 = 10.85. Find the sum of column 4 = 101.42.
4. Find factor by dividing the sum of column 4 into given basal area (70 square feet) = 70/101.42 = 0.69. Multiply number of trees, column 2 by the factor 0.69 to find adjusted number of trees. Record in column 5.
5. To check if adjusted distribution of number of trees renders the desired basal area, multiply column 3 by column 5 and record in column 6. The sum of this column should closely approximate the given basal area (70 square feet).

Figure 1.—Number of sawtimber trees per acre for a "Q" of 1.3 maximum tree dbh of 32 inches, and a basal area of 70 square feet.



APPENDIX II

Application of the Trial-and-error Method for Finding the Internal Rate of Return (IRR) for Site Quality Investments and Income Streams Shown in Table 12

The internal rate of return of an investment is that rate (percent) used to discount each term of an income stream to the year in which an investment is initiated and the results summed equal the beginning investment. To find the discount rate for our site-quality classes, we use the trial-and-error method and the IRR equation,

$$V_o = \frac{R_1}{(1+i)} + \frac{R_2}{(1+i)^2} + \ldots \frac{R_n}{(1+i)^n}$$

How do you proceed to find the correct discount rate to calculate an IRR? We have found that the graphic method provides a simple solution. We will use the high-quality-site data from table 12 to illustrate our method. The steps are as follows:

1. Substitute the values for V_o, R_1, R_2, and R_3 from table 12 in the IRR equation. Thus:

$$\$161.46 = \frac{\$13.72}{(1+i)} + \frac{\$50.32}{(1+i)^{10}} + \frac{\$394.13}{(1+i)^{12}}$$

2. Solve the discounting equation, using any reasonable rate. Find the value of $(1+i)$ for the selected rate from the interest tables for year 1, 10, and 12.

3. Compare the solution (we call this the NPW — *net present worth* of the income stream) with the initial investment. If the NPW is larger, select a higher rate and solve the equation, again using step 2.

4. Repeat the process, using a higher or lower rate to yield a result closer to the value of the initial investment.

5. Prepare a graph like that shown in figure 1. The X axis is labeled with a range of interest rates and the Y axis is labeled with a range of NPWs.

6. Draw the initial investment as a horizontal line.

7. Plot the NPWs previously calculated for the various discount rates.

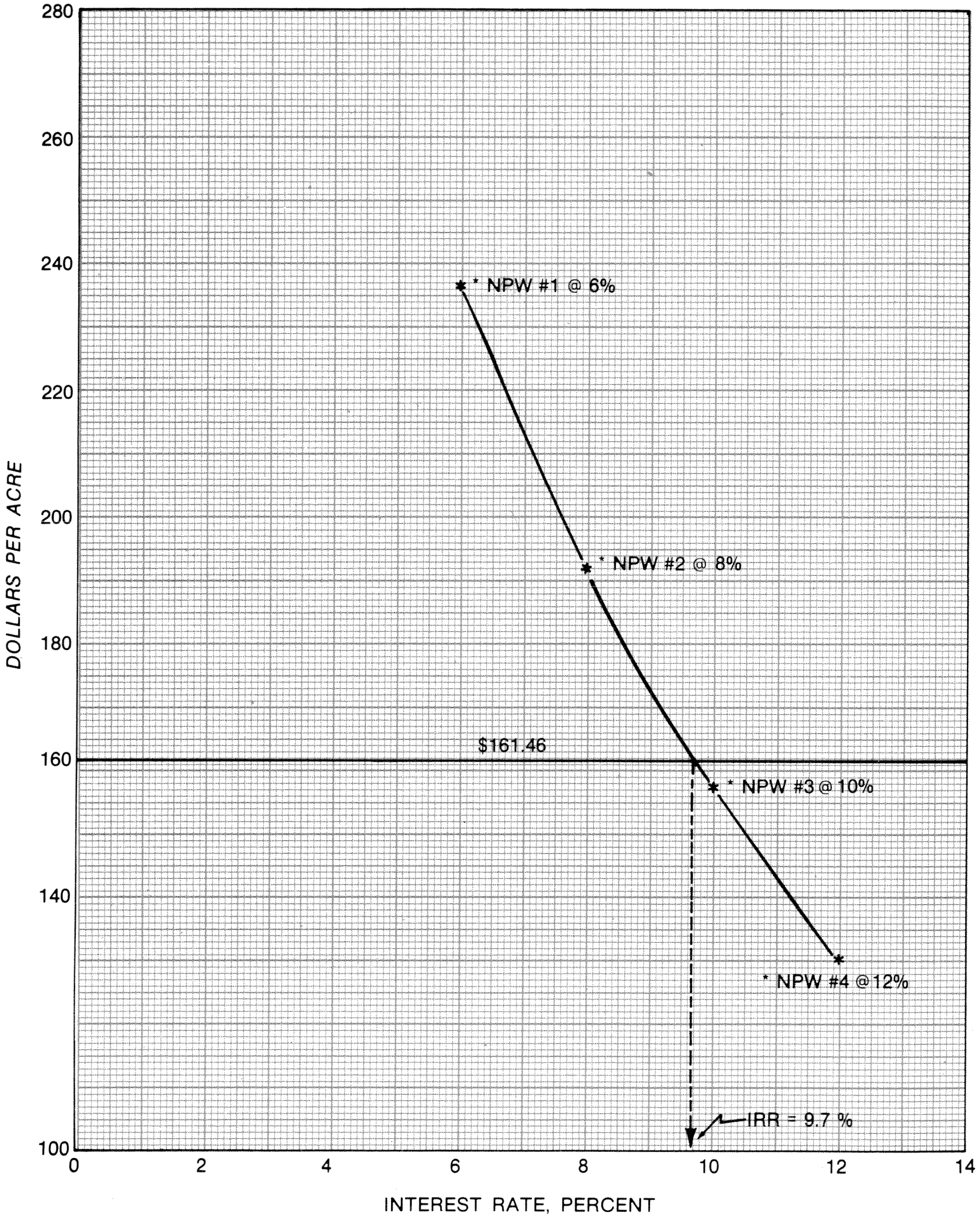
8. Calculate additional NPWs at different rates if you want additional plotting points to fill in the gaps.

9. When four or more points have been plotted around the horizontal line, connect with a smooth line.

10. From the intersection of the horizontal line and the curve, read vertically to the interest-rate scale. This is the interest rate that equates the income flow to the beginning investment or the IRR.

11. In figure 2 (appendix II), we used discount rates of 6, 8, 10, and 12 percent to plot the NPW curve. Using rates of 7, 9, and 11 would enable us to more accurately plot the curve and its point of intersection with the horizontal initial investment line.

Figure 2.—Graph for calculating internal rate of return (IRR) by the trial-and-error method. NPW is net present worth of the income stream.



APPENDIX III

Computing Net Future Value of an Investment When Intermittent Income is Reinvested

The flow of all net income attributable to an investment must logically be included in the net-future-value equation to measure the effectiveness or performance of the investment at some future point in time. References showing the application of net future value usually show application to periodic income and payments and costs for an investment. In practice, the net-future-value equation can be modified to account for any cost or income flow from the investment. In the illustration below we show how the equation is modified, using our site-quality information for the low-quality site presented in table 12.

To derive the true net future value, we use the initial value of the investment, $63.68/acre, the first cut of $14.65/acre, and the second cut of $23.24/acre. We know that the original investment was made 12 years ago, the first cut 11 years ago; and it has been 2 years since the second cut was made. What is the net future value of our initial investment in the low-quality site after 12 years if we desire a 5-percent rate of interest on the investment and reinvest all net income from the investment at the same rate? Using a modification of the net-future-value equation where:

$$V_n = V_o (1+i)^n - V_{o\,1} (1+i)^n - V_{o\,2} (1+i)^n$$

when:

V_n=Net future value.
V_o=Beginning investment.
$V_{o\,1}$=Net income of the first cut.
$V_{o\,2}$=Net income of the second cut.
n=Period in years of the investment or income.
i=Rate of interest.

or:

$$\begin{aligned} V_n &= \$63.68\ (1+.05)^{12} - \$14.65\ (1+.05)^{11} - \$23.24\ (1+.05)^{2} \\ &= 63.68\ (1.79586) - 14.65\ (1.71034) - 23.24\ (1.1025) \\ &= 114.36 - 25.06 - 25.62 \\ &= \$63.68 \end{aligned}$$

The net future value in our example is thus $63.68/acre. Or our investment 12 years ago must equal $63.68/acre to meet our goal of 5 percent on the initial investment and a like return on reinvested income from the investment. We note that the net future value would have been $114.36/acre if we had not reinvested the income from the two cuts. Further, net future value measures the value of our investment at the stated interest rate. Our low-site value at the end of 12 years was $140/acre or $76.32/acre above our goal of $63.68/acre. The undivided surplus or profit of $76.32/acre is the amount in excess of the investment goal of 5-percent rate of interest on the forest investment.

APPENDIX IV

List of common and scientific names of species referred to in this study:

Ash, white	*Fraxinus americana* L.
Aspen, bigtooth	*Populus grandidentata* Michx.
Basswood	*Tilia americana* L.
Beech, American	*Fagus grandifolia* Ehrh.
Birch, sweet	*Betula lenta* L.
Birch, yellow	*Betula alleghaniensis* Britton
Butternut	*Juglans cinerea* L.
Cherry, black	*Prunus serotina* Ehrh.
Cherry, pin	*Prunus pennsylvanica* L. f.
Cucumbertree	*Magnolia acuminata* L.
Dogwood, flowering	*Cornus florida* L.
Elm, American	*Ulmus americana* L.
Elm, rock	*Ulmus thomasii* Sarg.
Elm, slippery	*Ulmus rubra* Muhl.
Gum, black	*Nyssa sylvatica* Marsh.
Hemlock, eastern	*Tsuga canadensis* (L.) Carr.
Hickory, bitternut	*Carya cordiformis* (Wangenh.) K. Koch
Hickory, shagbark	*Carya ovata* (Mill.) K. Koch
Hophornbeam, eastern	*Ostrya virginiana* (Mill.) K. Koch
Hornbeam, American	*Carpinus caroliniana* Walt.
Locust, black	*Robinia pseudoacacia* L.
Magnolia, Fraser	*Magnolia fraseri* Walt.
Maple, red	*Acer rubrum* L.
Maple, striped	*Acer pennsylvanicum* L.
Maple, sugar	*Acer saccharum* Marsh.
Oak, chestnut	*Quercus prinus* L.
Oak, northern red	*Quercus rubra* L.
Oak, white	*Quercus alba* L.
Sassafras	*Sassafras albidum* (Nutt.) Nees.
Serviceberry, downy	*Amelanchier arborea* (Michx. f.) Fern.
Sourwood	*Oxydendrum arboreum* (L.) DC.
Yellow-poplar	*Liriodendron tulipifera* L.