The Rate of Value Increase

for Northern Red Oak, White Oak, and Chestnut Oak

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U.S.D.A. FOREST SERVICE RESEARCH PAPER NE-129
1969

NORTHEASTERN FOREST EXPERIMENT STATION, UPPER DARBY, PA.
FOREST SERVICE, U. S. DEPARTMENT OF AGRICULTURE
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INTRODUCTION

MANAGERS of timber-growing enterprises, like other businessmen, need to establish sound economic bases for their decisions. One of these bases is financial maturity, the point at which trees cease to earn an adequate return and should be cut. We have developed financial maturity information for northern red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and chestnut oak (*Q. prinus* L.), based on tree-growth and tree-quality data collected in West Virginia.

Foresters and landowners who are responsible for deciding when trees and stands should be cut may lack the necessary economic data to make this decision. As a result, they have had to rely heavily on such natural factors as growth, vigor, and log quality to determine when to harvest.

Though both natural factors and financial maturity must be considered in conjunction with other relevant management decisions, knowledge of financial maturity greatly improves the chance of making the most profitable decisions.

Financial maturity is arrived at when the rate of value increase of the tree or stand is at, or falls below, the rate of return desired by the timber grower. This rate of value increase depends on three factors: (1) the present value of the growing stock; (2) the prospective value of the growing stock, which includes consideration of growth increase in diameter as well as in merchantable height and possible improvement in quality; and (3) the estimated time between determinations of present value and prospective value. Given these data, the rate of value increase is determined by solving for r in the compound interest formula

$$(1 + r)^n = \frac{V_n}{V_0}$$

where r is the rate of interest.

n is the time period.

V_n is the prospective value.

V_0 is the present value.

We had to develop considerable basic data about lumber grade yields as well as prices to determine present value. We also had to obtain growth data to project the development of the tree over the time period used to establish prospective value.

DETERMINING PRESENT VALUE

Present value of a single tree is determined by its volume, lumber grade yield, and prices. The various units and standards that we used are described below.

Tree volume was expressed in board feet, International ¼-inch kerf rule.

Quality evaluations were based on log grades as developed by the U. S. Forest Products Laboratory for factory-lumber logs and defined in the field manual, *A guide to hardwood log grading (revised) (Ostrander and others 1965).*

Log-grade data were obtained from trees selected at random within the size classes needed. In addition to the three factory-lumber log grades (1, 2, and 3), a fourth category was recognized that included both construction and local-use-class logs. These logs, though better than cull logs, are too rough or knotty for lumber.

Lumber grade yields were obtained from the U. S. Forest Products Laboratory publication, *Hardwood lumber grades for standard lumber (Vaughan, Wollin, McDonald, and Bulgrin 1966).*

Prices were those reported in the *Hardwood market report (Lemsky 1962-66).* These prices were averaged over the 5-year period and the ratios (the price relations between these average prices for the various grades and the average price for No. 1 Common lumber) were computed (table 1).

In computing present value, the quality-index concept was used to determine the log value in terms of the amount and value of the lumber they contain.

Log-Quality Indexes and Tree-Quality Indexes

The quality-index concept (Q.I.), as developed by A. M. Herrick in 1946 and refined by other researchers since then, was used to put log grades on a lumber-value basis (*Herrick 1946*). Q.I. is a single number that expresses the relative value of a log or tree as determined by the amount of value of the different grades of 4/4 lumber (1 inch thick) that can be sawed from the log or tree (appendix I).

Thus two sets of data are essential in developing Q.I.: (1) lumber-grade yields by log grade, log diameter, and species; and (2) lumber-price relatives (price ratios with No. 1 Common as the base grade, derived from applicable regional price reports and averaged for a period of 5 years).

Using these data, we computed log-quality indexes for each species by log grade and diameter.

Next we developed tree-quality indexes based on the volume and quality index of each log in the tree (appendix II).

Developing Conversion Values

The versatility of tree-quality indexes is well illustrated in determining conversion values. Only the volume of the tree and the price of No. 1 Common lumber is needed to convert the tree-quality index to monetary terms, and the procedure is relatively simple.

As previously mentioned, tree volumes were calculated through use of the hardwood taper table and the International ¼-inch kerf rule.

Table 1.—*Lumber price relatives**

Species	Lumber grade					
	FAS	SEL	1C	2C	3A	3B
Red oak	1.74	1.65	1.00	0.67	0.59	0.40
White oak	1.90	1.81	1.00	.68	.59	.40
Chestnut oak	1.90	1.81	1.00	.68	.59	.40

*Based on 1962-1966 *Hardwood Market Report* prices for Appalachian hardwoods, f.o.b. mills in the area of Johnson City, Tennessee. 4/4 plain-sawed No. 1 Common grade was used as the reference.

The *Hardwood market report* of January 6, 1968 *(Lemsky 1968)* was used to obtain prices of 4/4 No. 1 Common lumber. Specifically, the Appalachian hardwood prices based on f.o.b. mill in the area of Johnson City, Tenn., were used. Prices were $122 per thousand for 4/4 No. 1 Common red oak and $120 per thousand for 4/4 No. 1 Common white oak and chestnut oak.

The per-thousand gross value of the lumber in trees of various diameters and merchantable heights was determined by multiplying the tree-quality index by the appropriate price per thousand.

To determine the net value per thousand of the lumber in the tree, it was necessary to deduct conversion costs. These are the costs involved in converting the standing tree into lumber. The bulk of these costs consists of labor and materials used in felling and bucking the trees, skidding and loading, other general logging costs, transportation, and milling costs involved in sawing the logs into lumber. For this study, average costs of $70 per thousand were used for 16-inch d.b.h. trees. Costs were adjusted and curved by tree diameters, and the resulting values were applied by tree d.b.h. class (table 2). We recognize that these costs may vary widely by logging chance and by sawmill.

Changes in conversion costs profoundly affect the rate of value increase because they affect the magnitude of the present conversion value that is to be carried forward into the future. In general, the lower the conversion costs, the lower the expected rate of value increase; and conversely, the higher the conversion

Table 2.—*Conversion costs for hardwood trees*

D.b.h. (inches)	Cost per thousand board feet
12	$78.85
14	74.50
16	70.00
18	65.70
20	61.35
22	57.00
24	53.50
26	52.25
28	51.95
30	51.85

costs, the higher the rate of return. These effects are somewhat dampened in the larger diameter classes. For example, the expected rates of value increase at various levels of conversion costs are:

	$60.00	*$70.00*	*$80.00*
16-inch d.b.h. — 1 log	7.3	8.1	9.6
30-inch d.b.h. — 1 log	1.5	1.6	1.6

Having determined the net value per thousand of the lumber in the tree by deducting the appropriate conversion costs, the next step was to calculate the conversion value (the present value of the tree). This was done by multiplying the net value per thousand by the appropriate tree volumes.

Thus, once tree-quality indexes are established, the calculation of present value can be summarized as follows:

1. Tree Q.I. × price for No. 1C per thousand = gross value per thousand.
2. Gross value per thousand — conversion cost = net value per thousand.
3. Net value per thousand × volume in tree = conversion value or present tree value.

DETERMINING PROSPECTIVE VALUE

Prospective value is the present value plus the increase in value due to diameter growth, the increase in merchantable height, and possible improvement in quality. In our study, prospective value was based on an assumed increase in tree value over the next 10 years. We also assumed that there would be no change in the market price of lumber. (An increase in price would result in a higher rate of value increase while a lower market price for lumber would result in a lower rate.)

D. b. h.-Growth Predictions

Tree growth within a species varies with several factors that the forest manager must recognize to apply growth to a given situation. For this reason tree growth was stratified by: (1) the ability of an area of forest land to grow trees (site quality); (2) the competitive condition of a tree in the stand (its vigor class); and (3) the size of the tree. Ten-year growth predictions were based on results of a study made of increment-core data *(Trimble 1960)*.

Diameter growth of sawtimber-size trees varied with species, tree-vigor class (definitions in appendix III), and site (definitions in appendix IV). The data were taken in well-stocked even-aged stands. The effect of stand density variations was not measured, but it is at least partially reflected in tree-vigor class. Only for vigor-class I trees did growth vary with d.b.h.: it decreased as the trees got bigger. Although this trend was detected only for vigor I trees, we know that this trend is a natural one, and we made adjustments so that it was reflected in the growth rates of the other vigor classes also (appendix V, tables 13, 14, 15, and 16).

In applying these diameter-growth predictions to the calculation of the rate of value increase, we made only two relatively minor assumptions: (1) that vigor classes would remain the same during the next 10 years, and (2) that vigor IV trees would never be considered as leave trees. Thus we did not calculate rate of value increase for this class.

Height-Growth Predictions

During the 10-year period for which value increases are projected, trees may increase in merchantable height. To guide the projection of log height increase, we made these assumptions:

1. Trees growing 2.0 inches d.b.h. and more during the 10-year period could potentially increase a full 16-foot log in merchantable height. And trees growing less than 2.0 inches d.b.h. in 10 years were restricted to a half-log increase in merchantable height.

2. Log-height increases are related to d.b.h. A tree that has a 16-foot merchantable stem at 20 inches d.b.h. has its merchantable length limited by stem breakup into crown, and its merchantable length will not increase with d.b.h. growth. For computation purposes, we set the following log-height-increase limitations:

Present d.b.h. (inches)	*Tree height classes that will not increase in height in next 10 years*
16	1-log trees
18	1- and 1½-log trees
20	1-, 1½-, and 2-log trees
22	1-, 1½-, 2, and 2½-log trees
24	1-, 1½-, 2-, 2½-, and 3-log trees
26	No increase in log height for any tree 26 inches d.b.h. or more.

3. Maximum log height used in the computation was 56 feet.

Quality-Improvement Predictions

Quality denotes value and in the development of a tree any improvement in quality will result in an appreciable increment in the rate of value increase. These assumptions guided us in our quality-improvement predictions:

1. The maximum butt-log grade improvement in the 10-year period was assumed to be one grade class. This may have been a conservative estimate for the better sites.
2. For red oak and chestnut oak, there was little prospect of grade improvement for butt-log grade 3 stems above 22 inches d.b.h. So we computed no grade improvement in these species above 22 inches; value increase was based only on d.b.h. and log-height increase. For white oak there was practically no improvement in butt-log grade 3 stems over 27 inches d.b.h.; so we computed no grade improvement above this size for grade 3 trees *(Trimble 1965)*.
3. In trees larger than 15 inches d.b.h. we computed no improvement in butt-log grade for trees with butt logs of construction or local-use grades. Such trees should be marked for early cutting.

Developing Prospective Value

Diameter growth, height growth, and quality improvement were considered to be important factors affecting the value increase of the tree over the 10-year period.

Diameter growth is given in the growth tables by site class and tree size. Future merchantable height and future log quality must be estimated by the observer, and guides for this purpose have been described. Through the use of the growth data and the assumptions on height and log quality changes, we can project the development of a tree and estimate its diameter, grade, merchantable height, and stumpage value at the end of the 10-year period. Several combinations of these factors are possible, such as: no increase in grade or log height, or an increase in grade or log height, or an increase in grade but not log height. Several other combinations are possible, limited only by our assumptions about these factors (table 3).

Assume that we have growing on a site index of 80 x 16-inch d.b.h., vigor I red oak tree with a butt-log grade of 2, and 24 feet of merchantable height. From table 13 in the appendix we can find a predicted growth rate for the 10-year period of 2.7 inches. Thus the predicted future d.b.h. of this red oak is 18.7 inches.

With regard to log grade, we find in our quality-improvement assumptions that this tree can improve one log grade in the 10-year period — the future tree can have a butt-log grade of 1 or 2. And with regard to height growth, we assumed an increase of a full 16-foot log; therefore we have three possible merchantable heights — 24, 32, and 40 feet. Thus six combinations of these factors exist:

Diameter (inches)	*Butt-log grade*	*Merchantable height (feet)*
18.7	2	24
	2	32
	2	40
	1	24
	1	32
	1	40

Conversion value (the prospective values for these possible combinations) is calculated in the same manner as the present value.

DETERMINING THE RATE OF VALUE INCREASE

Computation of the rate of value increase is based on the relationship between the present value and the prospective value 10 years hence, as depicted in the compound interest formula:

$$(1 + r)^n = \frac{V_n}{V_0}$$

Table 3.—*Determination of rate of value increase for 16-inch d.b.h. red oak, vigor I, site index 80**

Present				Future						
D.b.h. (inches) (1)	Butt-log grade (2)	Log height (feet) (3)	Tree value (dollars) (4)	D.b.h. (inches) (5)	Butt-log grade (6)	Log height (feet) (7)	Tree value (dollars) (8)	Ratio V_n/V_o (9)	Rate of value increase (percent) (10)	Ten-year value increase (dollars) (11)
16	1	16	3.01	18.7	1	16	6.57	2.183	8.1	3.56
16	2	16	.90	18.7	2	16	2.83	3.144	12.1	1.93
16	2	16	.90	18.7	1	16	6.57	7.300	22.0	5.67
16	1	24	3.75	18.7	1	24	8.52	2.272	8.6	4.77
16	1	24	3.75	18.7	1	32	9.46	2.523	9.7	5.71
16	1	24	3.75	18.7	1	40	9.75	2.600	10.0	6.00
16	2	24	.96	18.7	2	24	3.55	3.698	14.0	2.59
16	2	24	.96	18.7	2	32	3.77	3.927	14.7	2.81
16	2	24	.96	18.7	2	40	3.66	3.813	14.3	2.70
16	2	24	.96	18.7	1	24	8.52	8.875	24.4	7.56
16	2	24	.96	18.7	1	32	9.46	9.854	25.7	8.50
16	2	24	.96	18.7	1	40	9.75	10.156	26.1	8.79
16	1	32	4.05	18.7	1	32	9.46	2.336	8.9	5.41
16	1	32	4.05	18.7	1	40	9.75	2.407	9.2	5.70
16	1	32	4.05	18.7	1	48	9.73	2.402	9.2	5.68
16	2	32	.77	18.7	2	32	3.77	4.896	17.2	3.00
16	2	32	.77	18.7	2	40	3.66	4.753	16.9	2.89
16	2	32	.77	18.7	2	48	3.34	4.338	15.8	2.57
16	2	32	.77	18.7	1	32	9.46	12.286	28.5	8.69
16	2	32	.77	18.7	1	40	9.75	12.662	28.9	8.98
16	2	32	.77	18.7	1	48	9.73	12.636	28.9	8.96
16	1	40	3.77	18.7	1	40	9.75	2.586	10.0	5.98
16	1	40	3.77	18.7	1	48	9.73	2.581	9.9	5.96
16	2	40	.35	18.7	2	40	3.66	10.457	26.4	3.31
16	2	40	.35	18.7	2	48	3.34	9.543	25.3	2.99
16	2	40	.35	18.7	1	40	9.75	27.857	39.5	9.40
16	2	40	.35	18.7	1	48	9.73	27.800	39.4	9.38

*No computations are shown for trees with negative present or future stumpage values as in the case of trees with a butt-log grade of 3 or local-use and construction grade.

To continue our example of the 16-inch d.b.h. red oak used in the previous section, we can now calculate the rate of value increase. Given the units of present conversion value (table 3, column 4) and prospective conversion value (column 8), it is a relatively easy matter to determine the values for V_n/V_o (column 9) for the six possible future combinations of this 16-inch red oak 10 years in the future. Given these values for V_n/V_o, the rate of value increase (r) is determined by looking up the rates for these values in the compound-interest tables for $(1 + r)^{10}$ (column 10). Thus the rate of value increase for a 16-inch d.b.h., vigor-1 red oak tree with a butt-log grade of 2 and with 24 feet of merchantable height, growing on site index 80, can vary from 14.0 percent to 26.1 percent, depending on the changes in merchantable height and quality.

On the basis of diameter growth alone, this red oak can achieve an estimated 14.0 percent rate of value increase. Diameter growth plus an increase of 1 log merchantable height will result in an estimated 14.3-percent rate of value increase. However, the greatest gains in the rate are achieved when quality is increased one grade. Here the estimated rates are advanced 24.4 to 26.1 percent depending upon what additional height growth is made. This example illustrates the importance of quality improvement.

Throughout the development of the rate of value increase it was apparent that the resulting final tables would not depict the situation for all users of these tables and that the rate for any specific tree was but an estimation. In producing the quality indexes, a major factor in variation is the assumption of lumber-grade recovery of 4/4 factory-grade lumber. Few, if any, mills would duplicate exactly this recovery. They may increase or decrease the value of products recovered through producing different thicknesses or products. The use of a specific set of conversion costs (table 2) is another necessary generalization that may or may not fit the existing situation for a timber stand or logging crew.

For these and other reasons a presentation of specific rates of value increases would be illusionary and could possibly lead to improper usage. Instead, we decided ranges of rates were more useful. Thus tables 4 to 6 show the rate of value increase as a range of rates for a site index and a vigor class. Once the site index is determined for a stand, the cruiser need only find the diameter and vigor of the tree to determine the range of rate of value increase due to growth only that can be expected in the next 10 years. If the cruiser estimates that the tree will improve in quality to a higher butt-log grade class during this period he can look for a value increase rate in tables 4 to 6 under the section "Due to growth and quality increase."

INTERPRETING THE RATE-OF-VALUE-INCREASE CONCEPT

The rate of value increase is supplemental to the silvicultural and management considerations that must be made to ensure the proper development of present and future crops of timber. However, the rate-of-value-increase concept does reveal certain generalities about the financial development of a tree. These are:

Tree earning power decreases with increasing tree size.—A 14-inch d.b.h. vigor-1 red oak on site index 80 potentially can earn up to 30 percent annually over the next 10 years, based on growth alone, and up to 46 percent based on growth and possible quality (log grade) improvement. On the other hand, a 26-inch tree on the same site quality and of the same vigor class will earn about 2½ percent in growth alone and a maximum of 9 percent if a grade improvement occurs—an unlikely event in so large a tree.

Earning power is greatly increased by improvement in log grade.—As trees develop, many of them may be expected to improve in quality. Tables 4 to 6 illustrate the important gains to be made through quality improvement. For example, an 18-inch vigor-I red oak tree on an excellent site may increase in value up to 22 percent annually if a log-grade improvement takes place in the next 10 years (table 4). On the other hand, the rate of value increase due to growth alone would not exceed 12 percent over the same interval. Many small trees with grade-3 butt logs

Table 4.—*Expected rate of value increase for red oak trees, in percent*[1]

D.b.h. (inches)	Due to growth only				Due to growth and quality increase[2, 3]			
	Vigor I		Vigor III		Vigor I		Vigor III	
	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50
14	28-30	21	13-15	12-14	42-46	37-40	34-37	34-36
16	8-27	5-20	4-15	3-14	22-40	19-35	17-33	16-32
18	6-12	4- 8	3- 6	2- 5	16-22	14-19	12-17	12-16
20	5- 9	3- 5	2- 4	1- 3	13-17	11-14	10-13	10-12
22	4- 6	2- 3	2- 3	1- 2	11-45	9-43	9-42	8-41
24	3- 4	—	1- 2	—	9-10	—	8	—
26	2- 3	—	1	—	9	—	7- 8	—
28	2	—	0- 1	—	8- 9	—	7	—
30	2	—	—	—	8	—	7	—

[1] Based on 4/4 factory-grade lumber recovery. These rates can have a variation of 2 to 4 percent due to differences in location, volume estimates, and quality estimates.

[2] The high portion of the range in rates is due largely to low-grade trees that have a low present value and thus produce a relatively high rate of value increase when considered in the ratio V_n/V_o. For this reason, butt-log grade 3 logs have not been considered in the estimates "due to growth only."

[3] The high rates of value increase in the 22-inch diameter class are due to the improvement of butt-log grade 3 trees to butt-log grade 2.

Table 5.—*Expected rate of value increase for white oak trees, in percent*[1]

D.b.h. (inches)	Due to growth only				Due to growth and quality increase[2, 3]			
	Vigor I		Vigor III		Vigor I		Vigor III	
	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50
14	5-13	4- 8	4- 8	2- 6	17-26	15-21	15-21	14-19
16	5-10	2- 6	2- 6	0- 4	16-38	13-35	13-35	11-34
18	3- 7	1- 4	2- 4	0- 3	14-31	11-28	12-28	10-27
20	3- 6	0- 3	0- 3	0- 2	9-15	7-12	7-13	6-11
22	2- 4	0- 2	0- 2	0- 1	5-13	3-11	3-11	2-10
24	2- 3	—	1- 2	—	3-12	—	2-11	—
26	1- 2	—	1	—	1-12	—	0-11	—
28	1- 2	—	0- 1	—	11-12	—	11	—
30	1- 2	—	0- 1	—	12	—	11-12	—

[1] Based on 4/4 factory-grade lumber recovery. These rates can have a variation of 2 to 4 percent due to differences in location, volume estimates, and quality estimates.

[2] The high portion of the range in rates is due largely to low-grade trees that have a low present value and thus produce a relatively high rate of value increase when considered in the ratio V_n/V_o. For this reason butt-log grade 3 logs have not been considered in the estimates "due to growth only."

[3] The high rates of value increase in the 16- and 18-inch diameter classes are due to the improvement of butt-log grade 3 trees to butt-log grade 2.

Table 6.—*Expected rate of value increase for chesnut oak trees, in percent*[1]

D.b.h. (inches)	Due to growth only				Due to growth and quality increase[2]			
	Vigor I		Vigor III		Vigor I		Vigor III	
	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50	S.I. 80	S.I. 50
14	18-25	11-16	9-14	7-11	34-43	30-39	30-39	29-37
16	5-14	3- 8	2- 7	2- 5	21-25	19-22	18-21	17-21
18	3- 9	2- 4	2- 4	1- 3	15-27	14-23	13-22	12-21
20	3- 6	1- 3	1- 3	0- 2	11-15	8-12	8-12	7-11
22	3- 5	1- 2	1- 2	0- 1	8-11	6- 9	6- 9	5- 8
24	2- 3	—	1	—	6- 8	—	5- 7	—
26	2- 2	—	1	—	5- 7	—	4- 6	—
28	1- 2	—	0- 1	—	4- 7	—	4- 6	—
30	1- 2	—	0- 1	—	4- 6	—	3- 5	—

[1] Based on 4/4 factory-grade lumber recovery. These rates can have a variation of 2 to 4 percent due to differences in location, volume estimates, and quality estimates.

[2] The high portion of the range in rates is due largely to low-grade trees that have a low present value and thus produce a relatively high rate of value increase when considered in the ratio V_n/V_o. For this reason butt-log grade 3 logs have not been considered in the estimates "due to growth only."

have low or negative conversion values. When such trees are vigorous and are low grade only because they are small, they may be retained in the stand; but if they do not have the potential for grade improvement they should be removed as soon as possible. Though low-grade vigorous trees may earn a high interest rate, the actual monetary gain would be small and the stand earning power for a forest would be low when land-investment values are considered.

We emphasize that the probability of grade improvement decreases with increasing tree size. In stands in which thinnings or improvement cuttings have been made, the likelihood of future grade improvement for 22-inch trees would be slight indeed because the best quality stems would have been favored in previous markings *(Trimble 1965)*. In unmanaged stands the potential of log-grade improvement in the oaks is very low after trees reach 24 inches d.b.h.; and in deciding which trees of such diameters to leave, reliance should be placed almost solely on rate of return based on volume growth alone. In managed stands the critical d.b.h. is lower—perhaps about 20 inches—and would vary somewhat with the intensity of previous management.

Trees with greater merchantable height have, on the average, slightly higher earning rate potential if vigor class, butt-log grade, and site quality are the same.—This does not mean that a log-height increase in the near future increases tree earning power: it actually means that of two trees whose merchantable height is limited by the location of the crown, the one with the longer merchantable bole will increase more in value over a given period, other considerations being equal. The effect of log-height increase in a tree may increase the earning rate or it may decrease it. If the volume added in height growth has a positive conversion value, percent return is increased; if it has a negative value—as in the case of small grade-3 logs—it is decreased. In general, log-height increases will be limited to the smaller trees — less than 18 inches d.b.h. — and the volume added will decrease tree earning power over the 10-year period even though it may have potential for increasing it over a longer period.

MARKING GUIDES

Marking guides, based on tree earning power and to some extent on generally recognized marking principles, include: (1) guides for selection cutting under all-aged systems, for improvement cutting in previously unmanaged stands, and for sawlog thinnings in stands managed under an even-aged system; and (2) guides to setting average tree diameters for harvest cuttings (rotation tree size) under even-aged management.

For this latter use these guides can only be assumed appropriate for stands now at, or nearing, financial maturity. Extending the use of these evaluations beyond 10 to 15 years into the future is risky because probable changes in marketing and utilization practices may completely alter rates of return.

Because most oak stands that will be cut in the near future are some combinations of immature, previously unmanaged, or very lightly managed stands, the guides will be most useful in marking for partial cutting. And they probably will be useful in guiding improvement cuttings and thinnings in immature stands that will eventually be clearcut under some even-aged system. Used in such a way they must be considered in conjunction with residual stocking guides.

Partial Cutting

In all three species on all sites the trees to be discriminated against are: (1) culls and near culls, (2) trees with butt logs of local-use grade, (3) trees of any size in vigor-class IV, and (4) trees over 15 inches d.b.h. with butt logs of construction grade. Again, for all three species on all sites the trees to be favored and left are: (1) those with an imminent improvement in butt-log grade; (2) vigor-class I trees over vigor II and III, and vigor II over vigor III; (3) trees of greater merchantable length over trees of less merchantable length, other factors being similar; and (4) smaller diameter sawlog trees over larger sawlog trees with similar grade and vigor classes.

Rotation Size

After proper consideration of silvicultural and management needs, the rate-of-value-increase concept can also be utilized to determine rotation size in even-aged stands. These guides, presented separately by species in tabular form (tables 7, 8, and 9) are given for three interest-rate objectives—2, 4, and 6 percent. The diameters given are average stand diameters. In choosing a 2-percent interest rate objective, as in a case where multiple use applies, the first two columns of diameters would be used to determine the financial maturity. For example, given an area of site index 50, where trees would average about 1 log merchantable height, the top d.b.h. limit to leave for a 2-percent return on vigor-I red oak trees would be 23 inches (table 7). Trees grown larger than 23 inches would fail to provide a return of 2 percent. In this same example, where a 4-percent return is required, the top d.b.h. would be 19 inches; and for a 6-percent return the d.b.h. limit would be 17 inches.

Although the data are presented as guides for harvest cuttings under even-aged management, they can also serve as guides to partial cutting where no grade improvement is in prospect for the tree in question. We emphasize that the diameters in these tabular guidelines are based on value increases due to growth rate alone; therefore, they should be adjusted upward where potential log grade increase is involved.

The tabular data reflect earning power of trees with butt-log grades of 1 and 2. If trees with butt-log grades of 3 had been included, the smaller trees would have shown higher rates of return, which would have increased the financial maturity diameters. However, as previously stated, these butt-log grade 3 trees earn little money even though rates of return are high. Certainly above 15 inches in diameter they would be discriminated against in marking. The blanks in the tables mean that the rate of interest cannot be obtained with any size sawtimber trees of butt-log grades 1 and 2. If marking is made in areas of tree populations that fall largely under the category of low vigor, poor site, and small diameter, then the general guides given above under "partial cutting" should govern, and specific d.b.h. limitations are unimportant.

As a word of caution in interpreting tables 7, 8, and 9, users should remember that the interest rates are based on trees already existing in a stand and on their projected value increase over the next 10 years. Costs of growing the stand to sawtimber size were not considered. To illustrate this point, we doubt that oaks can be grown at cost to small sawlog size on site-index-50 land — even though in a stand already grown to small sawlog size, a number of individual stems will earn a low rate of interest over the next 10 years.

Table 7.—*Red oak diameters for financial maturity, in inches, based on value increase determined by growth rate alone*
(Based on trees with butt-log grades of 1 and 2)

Site index	Average log height	Percent return and vigor class					
		2		4		6	
		I	II	I	II	I	II
80	2½	28	25	22	21	20	18
70	2	26	24	22	20	19	17
60	1½	24	23	20	19	18	16
50	1	23	22	19	18	17	16

Table 8.—*White oak diameters for financial maturity, in inches, based on value increase determined by growth rate alone*
(Based on trees with butt-log grades of 1 and 2)

Site index	Average log height	Percent return and vigor class					
		2		4		6	
		I	II	I	II	I	II
80	2½	25	23	20	18	17	15
70	2	23	22	18	17	16	14
60	1½	21	20	17	16	15	—
50	1	19	18	16	15	14	—

Table 9.—*Chestnut oak diameters for financial maturity, in inches, based on value increase determined by growth rate alone*

(Based on trees with butt-log grades of 1 and 2)

Site index	Average log height	Percent return and vigor class					
		2		4		6	
		I	II	I	II	I	II
80	2½	26	23	20	19	17	16
70	2	24	22	19	18	17	16
60	1½	23	21	18	17	16	15
50	1	20	19	17	16	15	15

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APPENDIX I

Log-Quality Index

In equation form Q.I. appears as:

$$Q.I. = (\%\ FAS \times P.R._{FAS}) + (\%\ SEL \times P.R._{SEL}) + (\%_{\#1C} \times P.R._{\#1C}) \ldots + (\%_{\#3A} \times P.R._{\#3A})$$

in which —

% FAS means the percentage of the total volume of the lumber that could be sawed from the log or tree that would grade first and seconds.

$P.R._{FAS}$ means the standard price relative for FAS lumber *(Herrick 1956)*.

APPENDIX II

Tree-Quality Index

Tree quality index = (% of tree volume in 1st log × log $Q.I._{1st\ log}$) + (% of tree volume in 2nd log × log $Q.I._{2nd\ log}$) + (% of tree volume in nth log × log $Q.I._{n}$ log).

The percent of tree volume in each log is determined by means of a hardwood taper table, which provides the diameter inside bark at the small end of each log; and the International ¼-inch kerf volume table, which provides the volume of each log as well as the volume of the total merchantable height of the tree.

After tree-quality indexes were developed for each sample tree, regression analyses were used to develop tree Q.I. for each species by butt-log grade (for log grades 1, 2, and 3), diameter and merchantable height (tables 10, 11, and 12). Our examination of the log-grade data for trees with butt-log grades below 3 showed that in most cases such trees had a total tree grade below 3—regardless of species, diameter, or log height. Therefore, a tree Q.I. of 0.400 was assigned to all such trees (0.400 is a nominal value corresponding to the price relative for lumber grade 3B).

Table 10.—*Tree-quality index for red oak*

D.b.h. (inches)	Merchantable height in feet to an 8-inch diameter inside bark (d.i.b.) top					
	16	24	32	40	48	56
			BUTT-LOG GRADE 1			
16.0	0.834	0.795	0.757	0.718	—	—
18.0	.887	.848	.809	.770	0.731	—
20.0	.939	.900	.862	.823	.784	0.745
22.0	.992	.953	.914	.875	.837	.798
24.0	1.044	1.005	.967	.928	.889	.850
26.0	1.097	1.058	1.019	.980	.942	.903
28.0	1.149	1.110	1.072	1.033	.994	.955
30.0	1.202	1.163	1.124	1.085	1.047	1.008
			BUTT-LOG GRADE 2			
14.0	0.625	0.603	0.582	—	—	—
16.0	.652	.631	.609	0.587	—	—
18.0	.680	.658	.637	.615	0.593	—
20.0	.707	.686	.664	.642	.621	0.599
22.0	.735	.713	.692	.670	.648	.627
24.0	.762	.741	.719	.697	.676	.654
26.0	.790	.768	.746	.725	.703	.682
28.0	.817	.796	.774	.752	.731	.709
30.0	.845	.823	.801	.780	.758	.737
			BUTT-LOG GRADE 3			
12.0	0.440	0.431	—	—	—	—
14.0	.447	.438	0.430	—	—	—
16.0	.455	.446	.437	0.428	—	—
18.0	.462	.453	.445	.436	0.427	—
20.0	.470	.461	.452	.443	.434	0.425
22.0	.477	.468	.459	.451	.442	.433
24.0	.484	.476	.467	.458	.449	.440
26.0	.492	.483	.474	.465	.457	.448
28.0	.499	.491	.482	.473	.464	.455
30.0	.507	.498	.489	.480	.472	.463

Table 11.—*Tree-quality index for white oak*

D.b.h. (inches)	Merchantable height in feet to an 8-inch diameter inside bark (d.i.b.) top					
	16	24	32	40	48	56
			BUTT-LOG GRADE 1			
16.0	0.970	0.889	0.809	0.729	—	—
18.0	1.041	.961	.881	.800	0.720	—
20.0	1.113	1.033	.952	.872	.792	0.712
22.0	1.185	1.105	1.024	.944	.864	.783
24.0	1.257	1.176	1.096	1.016	.935	.855
26.0	1.328	1.248	1.168	1.087	1.007	.927
28.0	1.400	1.320	1.239	1.159	1.079	.998
30.0	1.472	1.391	1.311	1.231	1.150	1.070
			BUTT-LOG GRADE 2			
14.0	0.717	0.685	0.653	—	—	—
16.0	.730	.698	.666	0.634	—	—
18.0	.743	.711	.679	.647	0.615	—
20.0	.756	.724	.692	.660	.628	0.596
22.0	.769	.737	.705	.673	.641	.609
24.0	.782	.750	.718	.686	.654	.622
26.0	.795	.763	.731	.699	.667	.635
28.0	.808	.776	.744	.712	.680	.648
30.0	.821	.789	.757	.725	.693	.661
			BUTT-LOG GRADE 3			
12.0	0.526	0.503	—	—	—	—
14.0	.560	.537	0.514	—	—	—
16.0	.594	.571	.548	0.525	—	—
18.0	.628	.605	.582	.559	0.536	—
20.0	.662	.639	.616	.594	.571	0.548
22.0	.696	.673	.651	.628	.605	.582
24.0	.731	.708	.685	.662	.639	.616
26.0	.765	.742	.719	.696	.673	.650
28.0	.799	.776	.753	.730	.707	.684
30.0	.833	.810	.787	.764	.741	.719

Table 12.—*Tree-quality index for chestnut oak*

D.b.h. (inches)	Merchantable height in feet to an 8-inch diameter inside bark (d.i.b.) top					
	16	24	32	40	48	56
			BUTT-LOG GRADE 1			
16.0	0.930	0.888	0.846	0.804	—	—
18.0	.940	.898	.856	.814	0.773	—
20.0	.950	.909	.867	.825	.783	0.741
22.0	.961	.919	.877	.835	.793	.752
24.0	.971	.928	.888	.846	.804	.762
26.0	.982	.940	.898	.856	.814	.773
28.0	.992	.950	.908	.867	.825	.783
30.0	1.003	.961	.919	.877	.835	.793
			BUTT-LOG GRADE 2			
14.0	0.649	0.636	0.621	—	—	—
16.0	.667	.653	.638	0.624	—	—
18.0	.684	.670	.655	.641	0.627	—
20.0	.701	.687	.672	.658	.644	0.630
22.0	.718	.704	.690	.675	.661	.647
24.0	.735	.721	.707	.693	.678	.664
26.0	.752	.738	.724	.710	.695	.681
28.0	.769	.756	.741	.727	.713	.698
30.0	.786	.773	.758	.744	.730	.715
			BUTT-LOG GRADE 3			
12.0	0.529	0.529	—	—	—	—
14.0	.544	.544	0.544	—	—	—
16.0	.558	.558	.558	0.558	—	—
18.0	.572	.572	.572	.572	0.572	—
20.0	.586	.586	.586	.586	.586	0.586
22.0	.600	.600	.600	.600	.600	.600
24.0	.614	.614	.614	.614	.614	.614
26.0	.628	.628	.628	.628	.628	.628
28.0	.643	.643	.643	.643	.643	.643
30.0	.657	.657	.657	.657	.657	.657

APPENDIX III

Tree-Vigor-Class-Definitions

Vigor I.—A tree in this vigor class has a large, healthy, full crown in a dominant or co-dominant position. Half or more of the crown is exposed to direct sunlight. The crown is dense, with no evidence of disease or injury. Crown quality and position are more important than total length. The bark and twigs have good color and vigorous appearance.

Vigor II.—A tree in this vigor class has a fair-sized crown in a co-dominant position. Less than half the crown is exposed to direct sunlight. The crown is less dense and not so perfect as that of a vigor I tree. This class may also include a large-crowned tree that fails to meet the requirements of vigor I because of mechanical injury or dying limbs.

Vigor III.—A tree in this vigor class has a medium to small crown usually in an intermediate position. Only the tip is exposed to direct sunlight. The crown may be open, and may have some dead or broken limbs, or may be thinly foliated. This class also includes trees with fair to large crowns in a co-dominant position that cannot meet the requirements for a vigor II tree.

Vigor IV.—A tree in this class usually has a small crown in an overtopped position. This class includes all living trees that fail to meet the requirements of higher vigor classes.

APPENDIX IV

Site-Class Definitions

Site index of the oaks is the average height of dominant and co-dominant trees at 50 years of age. Site index was read for trees of measured total height and age from Schnur's curves *(Schnur 1937)*. We grouped site index by 10-foot site classes; i.e., site index 80 (75-84 feet), site index 70 (65-74 feet), site index 60 (55-64 feet), and site index 50 (45-54 feet).

APPENDIX V

10-Year D.B.H. Growth Rates

Table 13.—*10-year d.b.h. growth rates in inches for site index 80 oak*

Initial d.b.h. (inches)	Vigor-class I			Vigor-class II			Vigor-class III			Vigor-class IV		
	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak
12	3.0	2.1	2.7	2.2	1.6	2.1	1.2	1.1	1.2	0.6	0.6	0.6
14	2.8	2.0	2.5	2.1	1.5	1.9	1.1	1.1	1.1	.5	.5	.5
16	2.7	1.9	2.4	2.0	1.4	1.8	1.1	1.0	1.0	.5	.5	.5
18	2.5	1.8	2.2	1.9	1.4	1.7	1.0	1.0	.9	.5	.5	.5
20	2.4	1.7	2.1	1.8	1.3	1.6	1.0	.9	.9	.5	.5	.5
22	2.2	1.6	2.0	1.7	1.2	1.5	.9	.8	.9	.4	.4	.4
24	2.1	1.5	1.9	1.6	1.1	1.4	.9	.8	.8	.4	.4	.4
26	2.0	1.4	1.8	1.5	1.1	1.3	.8	.7	.8	.4	.4	.4
28	1.8	1.3	1.6	1.4	1.0	1.2	.7	.7	.7	.3	.3	.3
30	1.6	1.2	1.5	1.2	.9	1.1	.7	.6	.6	.3	.3	.3
32	1.5	1.1	1.4	1.1	.8	1.1	.6	.6	.6	.3	.3	.3

Table 14.—*10-year d.b.h. growth rates in inches for site index 70 oak*

Initial d.b.h. (inches)	Vigor-class I			Vigor-class II			Vigor-class III			Vigor-class IV		
	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak
12	2.7	1.8	2.3	2.0	1.4	1.8	1.2	1.0	1.1	0.6	0.6	0.6
14	2.5	1.7	2.1	1.9	1.3	1.7	1.1	1.0	1.0	.5	.5	.5
16	2.4	1.6	2.0	1.8	1.2	1.6	1.1	.9	.9	.5	.5	.5
18	2.2	1.5	1.9	1.6	1.2	1.5	1.0	.9	.9	.5	.5	.5
20	2.1	1.4	1.8	1.5	1.1	1.4	.9	.8	.8	.4	.4	.4
22	1.9	1.3	1.6	1.4	1.0	1.3	.8	.7	.8	.4	.4	.4
24	1.8	1.2	1.5	1.3	.9	1.2	.8	.7	.7	.4	.4	.4
26	1.6	1.1	1.4	1.2	.9	1.1	.7	.6	.7	.3	.3	.3
28	1.4	1.0	1.2	1.1	.8	1.0	.6	.6	.6	.3	.3	.3
30	1.3	.9	1.1	1.0	.7	.9	.6	.5	.5	.3	.3	.3
32	1.1	.7	.9	.8	.5	.7	.5	.4	.4	.2	.2	.2

Table 15.—10-year d.b.h. growth rates in inches for site index 60 oak

Initial d.b.h. (inches)	Vigor-class I			Vigor-class II			Vigor-class III			Vigor-class IV		
	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak
12	2.3	1.4	1.8	1.7	1.1	1.4	1.1	0.9	0.9	0.5	0.5	0.5
14	2.2	1.4	1.7	1.6	1.1	1.4	1.1	.9	.9	.5	.5	.5
16	2.0	1.3	1.6	1.5	1.0	1.3	1.0	.8	.8	.5	.5	.5
18	1.9	1.2	1.5	1.4	.9	1.2	.9	.7	.8	.4	.4	.4
20	1.7	1.1	1.4	1.3	.9	1.1	.8	.7	.7	.4	.4	.4
22	1.6	1.0	1.3	1.2	.8	1.0	.8	.6	.7	.4	.4	.4
24	1.4	.9	1.1	1.0	.7	.9	.7	.6	.6	.3	.3	.3
26	1.3	.8	1.0	.9	.6	.8	.6	.5	.5	.3	.3	.3
28	1.1	.7	.9	.8	.5	.7	.5	.4	.5	.3	.3	.3
30	1.0	.6	.8	.7	.5	.6	.5	.4	.4	.2	.2	.2

Table 16.—*10-year d.b.h. growth rates in inches for site index 50 oak*

Initial d.b.h. (inches)	Vigor-class I			Vigor-class II			Vigor-class III			Vigor-class IV		
	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak	Red oak	White oak	Chestnut oak
12	2.0	1.2	1.5	1.4	1.0	1.2	1.1	0.8	0.9	0.5	0.5	0.5
14	1.8	1.1	1.3	1.3	.9	1.1	1.0	.8	.8	.5	.5	.5
16	1.7	1.0	1.2	1.2	.8	1.0	.9	.7	.7	.4	.4	.4
18	1.5	.9	1.1	1.1	.7	.9	.8	.6	.6	.4	.4	.4
20	1.4	.8	1.0	1.0	.7	.8	.8	.6	.6	.4	.4	.4
22	1.2	.7	.9	.9	.6	.7	.7	.5	.5	.3	.3	.3
24	1.1	.6	.8	.8	.5	.7	.6	.4	.5	.3	.3	.3
26	.9	.5	.7	.6	.4	.6	.5	.4	.4	.2	.2	.3

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