SOME NATURAL FACTORS THAT GOVERN

THE MANAGEMENT OF OAKS

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Plateau
T.M.

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SUMMARY & CONCLUSIONS

A study was made to determine and evaluate some of the natural factors that affect management of mixed oak stands in the Northern Appalachian area. Data were collected on 71 oak plots covering a wide range of forest conditions within the study area.

This study showed that a knowledge of site quality is important to successful management. The results indicate that management systems, growing-stock levels, and cutting cycles should be tailored to the site for best results. To help identify site quality in the field, the four major factors that affect it were identified, evaluated, and presented in tabular form for easy field use.

The composition of oak stands, their structure, and their reproduction are affected by site quality. The proportion of oaks in the stand decreases with improved site; the variety of other forest-tree species increases.

Stand structure and tree size vary with site quality. There are more total stems per acre on poorer sites. Most of these are in the very small, unmerchantable diameter classes. There are more of the larger trees per acre (over 5.0 inches d.b.h.) on the better sites.

Established oak reproduction is most abundant on medium to poor sites. On the best sites, oak reproduction is in severe competition with faster-growing species. This offers a clue to the opportunity for oak management and the intensity of silvicultural measures that may be necessary to help establish oak reproduction.

Tree vigor influences tree growth and may be used as a guide in marking. The relative growth rates by vigor class indicate that, for maximum productivity, stands should be thinned so that Vigor III and IV trees are eliminated or converted to higher vigor.

Since site quality also influences growth, average growth rates were determined by tree vigor and site-index classes. These rates indicate that on good sites frequent thinnings may be made because even the low-vigor trees can reach merchantable size. On the poorer sites, low-vigor trees may never reach merchantable size before they die out. On these poor sites, intensive management can do less to increase stand growth.

The grade of a tree, that is, its product-conversion quality, is influenced by its size. There are indications, however, that some species clear up faster than others under identical conditions of age and size. Species appear to have a built-in grade potential just as they have a built-in growth potential.

The data on site, stand structure and composition, growth by vigor and site classes, and tree grades can all be applied in practical stand management. They provide a basis for determining the relative value of oak stands growing on different sites. They provide a reference point for management. They isolate some of the basic natural factors that govern the management of oaks and answer some of the questions that confront the practicing forester today.

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CONTENTS

THE PROBLEM & THE STUDY

The oaks are the most important species group in the Appalachian hardwood forests. In West Virginia, oaks provide more than half of the lumber produced in the State. In addition, they provide a large portion of the mine timbers and specialty products.

Some general recommendations for stand-improvement methods are available (11).[1] However, information on the silviculture and management of oak stands is incomplete. Information is lacking on how to determine the productivity of oak sites, how to make reliable estimates of growth, and how to determine which oak species are best adapted to each site.

Thus a study was made of oak stands in the Northern Appalachian section of West Virginia and western Maryland. The results of this study give some clues to the basic factors that affect growth, composition, and quality of oak. These findings will help answer many of the forest manager's needs. Because this study area is similar to millions of acres of oak forests throughout the Appalachians, the results should have wide application.

The stands.--In the four counties[2] of northeastern West Virginia and western Maryland where this study was made, northern red oak is the principal oak. It is found in mixture with the other oaks and hardwoods (13, 14); and it occurs to a limited extent in mixture with almost pure stands of chestnut oak and scarlet oak along ridges, on southern and western slopes, and in rocky areas of shallow soils. It often occurs in mixture with black oak, white oak, and hickory. On moist sites, scattered red oak trees occur in mixture with beech, yellow-poplar, black cherry, and sugar maple.

The steep topography and broken terrain of this area produce great variety in elevation and exposure (fig. 1). These in turn cause varieties in forest site quality that result in a complex heterogeneous hardwood mixture without clear-cut forest-type lines. Fire, cutting, and the death of the chestnut have further complicated the species composition.

The major oak species are northern red oak (*Quercus rubra* L.), and chestnut oak (*Quercus prinus* L.), with scat-

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[1]Underlined numbers in parentheses refer to Literature Cited, page 28.

[2]Tucker, Randolph, and Preston Counties in West Virginia and Garrett County in Maryland.

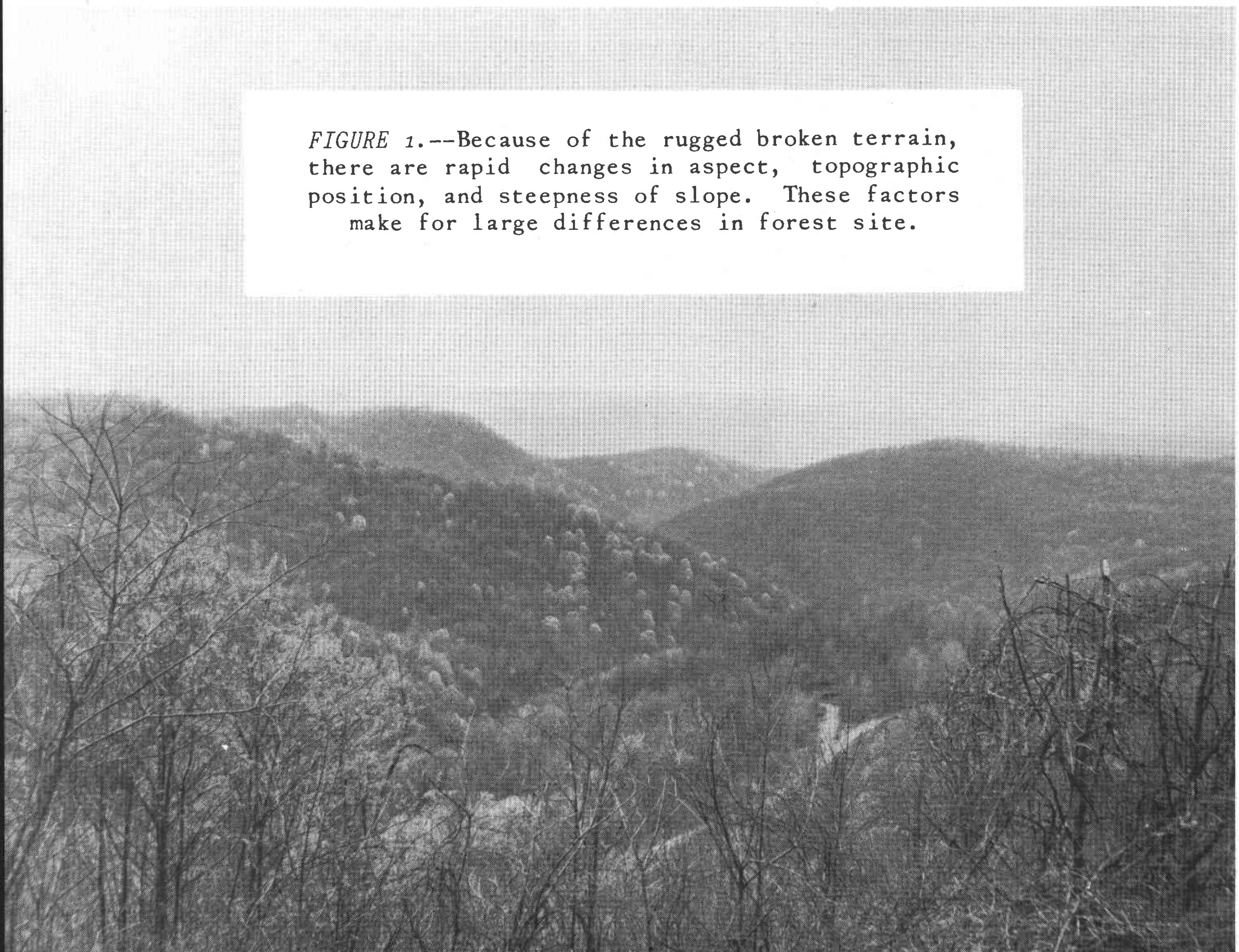

FIGURE 1.--Because of the rugged broken terrain, there are rapid changes in aspect, topographic position, and steepness of slope. These factors make for large differences in forest site.

tered white oak (*Quercus alba* L.), and only small amounts of scarlet oak (*Quercus coccinea* Muenchh.) and black oak (*Quercus velutina* Lam.).

The study.--In broad terms, the objectives of this study were: (1) To learn how to determine the productivity of oak sites from land features; (2) to learn something of the composition and reproduction of natural oak stands under a variety of site conditions; and (3) to define and measure the factors that influence growth and quality of oak trees and stands.

This type of information will help the practicing forester determine: (1) The comparative value of different forest areas for producing a timber crop; (2) which individual trees to cut or leave in marking for a sale; (3) the species of oak to favor on a particular site; and (4) how much an area is growing in volume and value.

Data were collected over the study area on 71 plots covering a range of soil and topographic conditions. Stands were sampled only if they were well-stocked and even-aged, showing no evidence of recent fire or grazing, and were old enough (usually at least 40 years old) so that they expressed site quality.

RESULTS

SITE QUALITY A CONTROLLING FACTOR IN MANAGEMENT

The data that follow will show how the composition of the stands, the size of the timber, and growth and grade are correlated with the productivity of the site. The volume yield and the dollar return are also strongly affected by the inherent productivity of the site.

This makes site index[3] a key factor in the management of oaks. Therefore, one of the first objectives of the study was to devise a reliable and workable system for identifying site index in the field, which would make the data more useable to practicing foresters.

But measuring site index by the conventional use of site-index curves is limited. A large proportion of existing stands are either uneven-aged, understocked, or too young to express site index. Any one of these conditions invalidates the use of height-over-age procedures for estimating site quality. For this reason, a more practical system had to be devised for estimating the productivity of forest land (17, 19).

Analysis showed that the four factors from which site quality can be estimated directly in the field were; (1) aspect; (2) topographic position--that is, whether on a lower slope, a middle slope, a ridgetop, or elsewhere; (3) steepness of the slope; and (4) soil depth to bedrock. The

[3]Site index of oaks is the average height of dominant and co-dominant trees at 50 years of age.

relationship between site index and the four factors involved was expressed in an equation (Appendix I).

For convenience, the site indexes of all conditions covered in this study were computed from the equation and are given in tabular form (Appendix I). Table 1 shows in simplified form the relationship between site index and the factors affecting site quality. These tables apply to areas

Ridge top?
Shelf on slope?
Bottom?
Broad, flat ridge top? Plateau?

Table 1.--Generalized relationships between land factors and site-index class for red oak

Aspect	Total soil depth[1]	Estimates of site index											
		Bottom of slope at slope percent of--			1/3 way up slope at slope percent of--			2/3 way up slope at slope percent of--			Upper slope at slope percent of--		
		0-20	21-40	41+	0-20	21-40	41+	0-20	21-40	41+	0-20	21-40	41+
	Feet												
N, NE & E	1-2	[2]90	80	70	80	70	60	70	70	60	70	60	50
	2-3	[2]100	90	80	90	80	70	80	80	70	80	70	60
	3+	100	90	80	90	90	80	80	80	70	80	70	60
NW & SE	1-2	80	70	60	70	60	60	70	60	50	60	60	50
	2-3	90	80	70	80	70	60	70	70	60	70	60	50
	3+	90	80	70	80	80	70	80	70	60	70	60	60
S, SW, & W	1-2	70	60	50	70	60	50	60	50	50	50	50	40
	2-3	80	70	60	70	60	60	70	60	50	60	60	50
	3+	80	70	60	80	70	60	70	60	60	60	60	50

[1]Areas with less than 1 foot of soil generally have low site-index values (50 to 30).

[2]Oak stands seldom occur on these excellent sites (site-index classes 90 and 100).

of medium-textured, well-drained soils derived from sandstone and shale, which cover conditions under which most of the oak forests in the area grow. In areas with different geology, soils or climate, other factors may become better indicators of site index (3, 5, 6, 8).

STAND COMPOSITION & STRUCTURE VARY WITH SITE QUALITY

Since this was a study of oak, the first prerequisite in choosing plots was that they include several oaks in the dominant canopy. All stands that did not satisfy this condition were passed up. Thus in all cases, particularly on areas of site indexes above 65, the stand composition reported in this study shows a higher percentage of oaks in relation to other species than would be shown by a random sample. In site index 80 (75-84) and above, oak is not a common component of the stand. However, the trend of composition with site index is a true one even though the de-

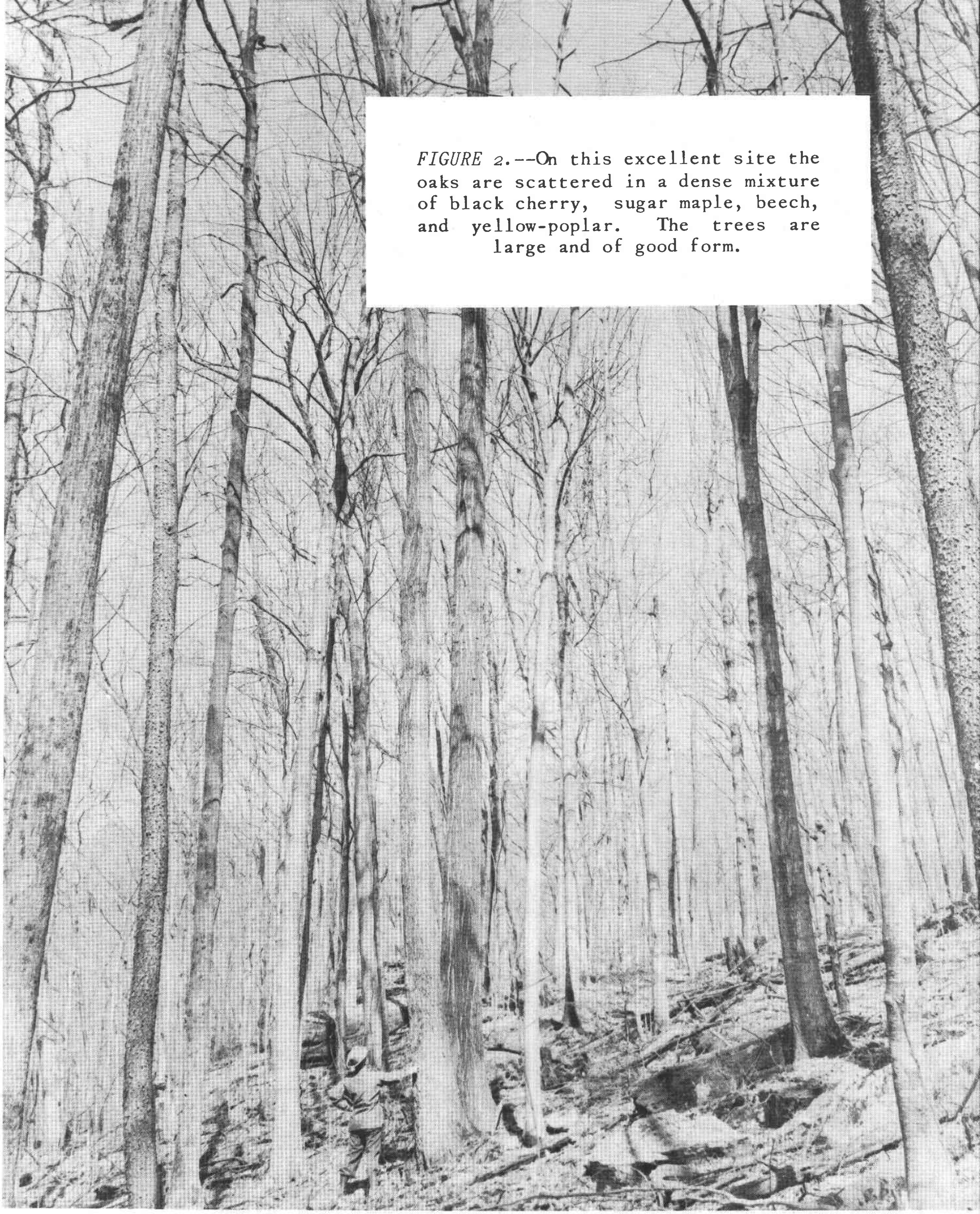

FIGURE 2.--On this excellent site the oaks are scattered in a dense mixture of black cherry, sugar maple, beech, and yellow-poplar. The trees are large and of good form.

cline in number of oaks with increasing site index, as shown by this study, may not be exact. For this phase of the study, 65 oak stands were sampled.

Species distribution.--The average number of trees per acre by species in each site-index class (Appendix II) shows a trend between site index and stand composition. Tables 2 and 3 summarize some of the more important relationships. These are illustrated in figures 2 and 3.

Several conclusions can be drawn from the data on species distribution (tables 2 and 3) while making due allowance for the biased sample: (1) The proportion of oak decreases with increasing site index. (2) Site index influences strongly the relative proportion of the different oak

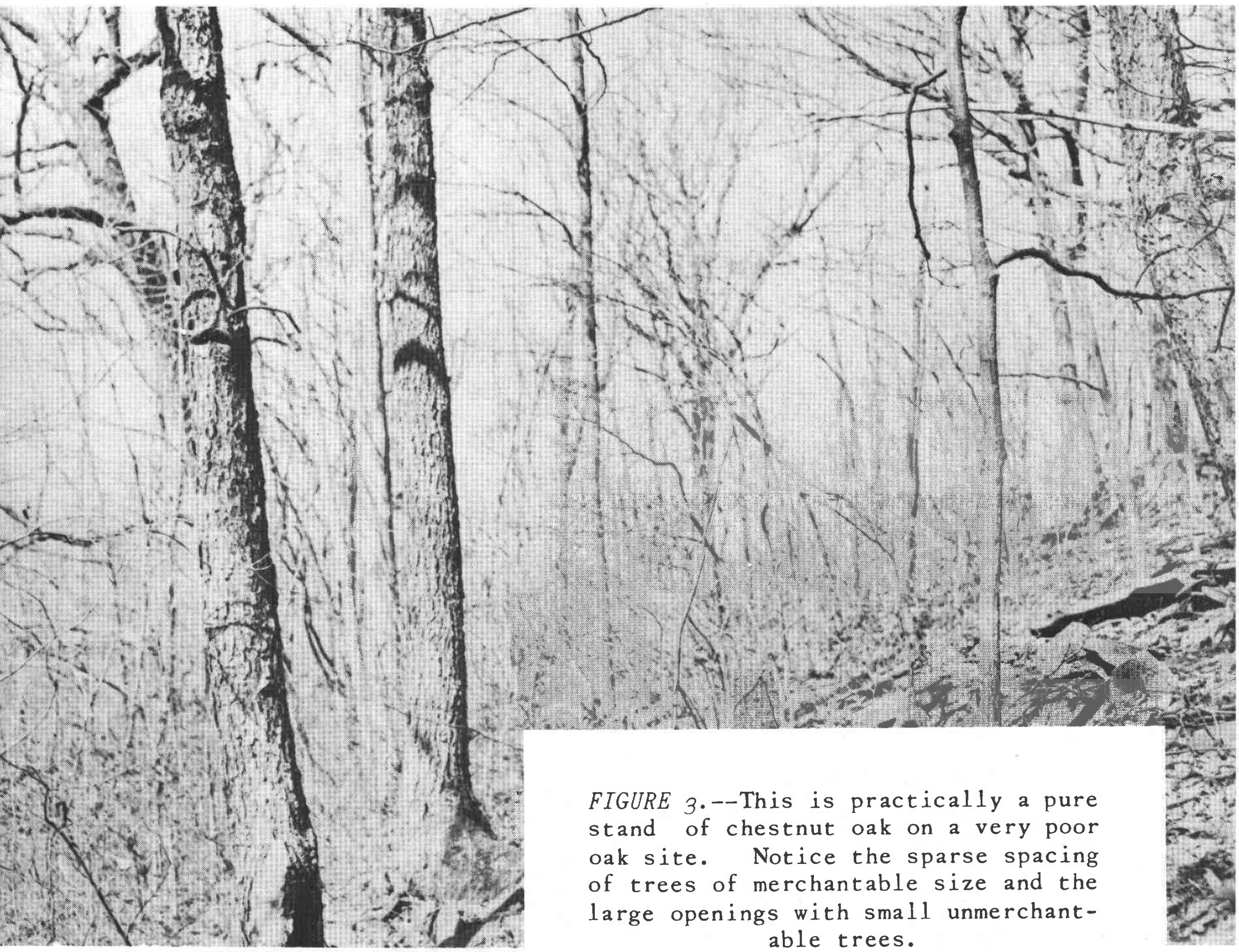

FIGURE 3.--This is practically a pure stand of chestnut oak on a very poor oak site. Notice the sparse spacing of trees of merchantable size and the large openings with small unmerchantable trees.

Table 2.--Stand composition of trees 5.0 inches d.b.h. and over

Site index	Plots	Species	Trees per acre	Oaks	
				Per acre	Percent of total
	No.	No.	No.	No.	Percent
40	4	10	126	104	82
50	5	13	161	132	82
60	17	27	198	122	62
70	24	27	203	96	47
80	15	25	185	60	32

Table 3.--Number of trees per acre by species and site-index class (5.0 inches d.b.h. and over)

Species	Site-index class				
	40	50	60	70	80
Red oak	11	20	54	69	35
Chestnut oak	74	32	34	17	12
White oak	11	38	13	5	11
Other oaks[1]	8	42	21	5	1
Others[2]	22	29	76	107	126

[1]Scarlet, black, and pin oaks.

[2]Primarily hardwoods, with some pine or hemlock.

species found in mixture, Red oak increases in proportion to other oaks as site index increases. Chestnut oak, on the other hand, shows a steady decrease as the site improves. Scarlet oak is also definitely a poor-site tree. (3) The number of trees per acre (5.0 inches d.b.h. and over) increases with increasing site quality up to about site index 70. (This statement can be made in view of the fact that stand ages averaged approximately the same.) (4) The variety of species increases with improving site. (5) Among the other species, sugar maple, basswood, white ash, yellow-poplar, and black cherry are better-site species; and hickory, red maple, and black locust are found over the range of site indexes (Appendix II).

Crown distribution.--The per-acre tree tally by site indexes was separated into dominant, co-dominant, and subdominant (intermediate and suppressed) trees (table 4). The number and percentage of trees in the dominant position re-

Table 4.--Crown position of trees in oak stands, by site index

(5.0 inches d.b.h. and over)

Site index	Plots	Dominant		Co-dominant		Sub-dominant		Total
		Trees per acre	Percent of total	Trees per acre	Percent of total	Trees per acre	Percent of total	
	No.	No.	Percent	No.	Percent	No.	Percent	No.
40	4	4.9	3.9	102.3	81.3	18.6	14.8	125.8
50	5	5.0	3.0	116.0	72.0	40.0	25.0	161.0
60	17	10.1	5.1	133.7	67.4	54.5	27.5	198.3
70	24	6.5	3.2	131.4	64.7	65.3	32.1	203.2
80	15	6.3	3.4	99.8	54.0	78.9	42.6	185.0

Table 5.--Number of trees per acre by site index at age 50 years[1]

Site index	All trees 0.25 inch d.b.h. and larger	All trees 5.5 inches d.b.h. and larger	All trees 10.5 inches d.b.h. and larger	Trees 0.25-5.5 inches d.b.h.
40	802	155	0	647
50	623	211	1	412
60	482	252	11	230
70	374	249	26	125
80	290	222	56	68

[1]From Schnur (15).

Table 6.--Natural reproduction under oak stands sampled

Site index	Plots	Trees per acre, all species	Oak reproduction			Trees 5.0 inches d.b.h. and over that are oaks
			Per acre	Percent of all species	Relative frequency	
	No.	No.	No.	Percent		Percent
40	4	3,600	1,700	47	1st	82
50	5	4,800	1,480	30	1st	82
60	17	4,200	1,100	26	1st	62
70	24	3,000	400	14	3rd	47
80	15	3,000	80	3	9th	32

Table 7.--Distribution of oak reproduction per acre, by site index

Site index	Plots	Total per acre	Red oak	Chestnut oak	White oak	Scarlet oak
	No.	No.	No.	No.	No.	No.
40	4	1,700	0	1,100	300	300
50	5	1,480	400	440	560	80
60	17	1,100	520	400	60	130
70	24	400	58	308	34	0
80	15	80	54	0	26	0

mains relatively constant across the range of site indexes. The actual number and the proportion of suppressed trees above 5.0 inches d.b.h. increases with the improvement in site (table 4). It is interesting to note that the increase in total number of trees of this size with increasing site index is largely due to this increased number of suppressed trees. Apparently the poor sites can support few suppressed trees. When they drop below the co-dominant position they die out.

Diameter distribution.--The diameter distribution of the oak stands at any age reflects the productivity of the site. The number of larger trees (10.5 inches d.b.h. and up) increases with improved site quality (table 5). The size of the trees, plus the different growth rate by sites (table 8), suggest a different cutting cycle for areas with different site indexes.

It has been established in this and other studies (12, 15) that the total number of stems per acre (0.25 inches d.b.h. and up) is greater for areas with the lower site indexes. As shown by table 5, most of these trees on the poorer sites are in the very small unmerchantable diameters (between 0.25 and 5.5 inches).

Natural reproduction.--The kind and amount of natural reproduction on each of the sites visited were sampled. Analysis shows a trend between the number and kind of established reproduction and site index. Since the stands sampled were composed 30 percent or more of oak species, the nature of the reproduction under them may indicate the opportunity for oak to become a strong component of future stands. This is an important point in the management of Appalachian hardwoods. Practicing foresters are concerned because many oak stands are not reproducing themselves in this region.

Deer?

Natural oak reproduction, like the distribution of oak trees, is more prevalent on the medium to poor sites. This provides a clue to the sites on which oak may be able to maintain itself.

In the stands sampled, oak forms a decreasing proportion of the total reproduction as site quality improves (table 6). At about site index 65, oak reproduction drops from first place. It is interesting to note that for site index 80, only 3 percent of the total established reproduction was oak, though oak trees averaged 32 percent of the overstory. It may be pertinent to compare the relative amount of oak reproduction by site-index with the site-index frequency of the oak stands sampled (fig. 8). Both the dominant position of oak reproduction and the number of oak stands sampled start dropping off at about site index 65.

This could indicate that under natural conditions the oaks will maintain themselves pretty well on areas with a site index of 65 or lower. On better sites, competition from faster growing or more tolerant species make conditions less conducive to the establishment of the oaks. Of course, to the extent that management practices can modify the establishment of natural reproduction, so will the range of oak stands be modified.

A breakdown of oak reproduction by species is given in table 7. It indicates that some oak reproduction occurs over a wide range of site quality; with red oak absent on the areas of lowest site index and scarlet oak absent from the better sites. This is a generally accepted relationship, and it is borne out by stand tables of the area.

Discussion Of Stand Composition & Structure As Affected By Site Quality

The relationship between species and site index provides useful guides to improvement cuttings and thinnings in these even-aged oak stands. Whereas the oaks will grow over a wide range of sites, they are better adapted to maintaining and reproducing themselves on sites of medium and low quality. In making intermediate cuttings, the forest manager should consider the suitability of the individual species to the site before selecting crop trees.

The crown distribution indicates why thinnings can be made frequently on the better sites without loss in growth. The better sites carry a preponderance of sub-dominant trees that have very slow growth rates. Cutting these trees does not reduce the ability of the stand to make full use of the site. Many trees will reach merchantable size before they die out. Under management they can be salvaged. On the poorer sites most of the sub-dominant trees die out before they reach merchantable size; thus unless there is a market for very small material, it may not be profitable to remove them.

The diameter distribution in oak stands indicates that in addition to the increased number of merchantable trees per acre on the better sites, there will be a larger number of bigger trees. This will permit more frequent intermediate and harvest cuts.

GROWTH, YIELD, & VALUE OF OAK STANDS ARE RELATED TO SITE QUALITY

Estimating growth and yields of stands.--Available yield tables that indicate the relative yields of stands by site-index classes provide a usable basis for determining those sites on which forest management will yield the greatest dividends. As the need for forest products brings pressure for better forest management, it is logical to believe that the system of management will eventually be related to site quality, since it so greatly affects the yield over a period of time and thus influences the frequency of cut and intensity of management.

As oak forests are put under management, the need for tailoring their management to fit the inherent limitations as well as the potentialities of each site will become more apparent. Table 8 gives yields per acre at 50 years for different site indexes. These are yield-table values. Though their use in predicting actual yields is subject to

Table 8.--Growth and yield per acre at 50 years, by site-index classes[1]

Site index	Yield			Mean annual growth		
	Cubic[2] feet	Board[3] feet	Cords[4]	Cubic[2] feet	Board[3] feet	Cords[4]
40	1,060	1,400	12	21	28	0.25
50	1,600	3,250	19	32	65	.38
60	2,230	6,300	26	45	126	.52
70	2,830	9,750	33	57	195	.67
80	3,450	13,750	41	69	275	.81

[1]Adapted from Schnur (15).

[2]Growth of merchantable stand, including bark, to a 4-inch top inside bark.

[3]International rule, 1/8-inch kerf, to a 5-inch top inside bark, including all trees having at least one 16-foot log.

[4]85 cubic feet per cord including bark, to a 4-inch top outside bark.

considerable error, it is believed they do indicate relative yields. There are large differences in volume between site-index classes: from site index 50 to 70, there is a 200 percent increase in board-foot volume. Table 8 also shows the differences in productivity between sites in terms of growth. These growth and yield figures are the average for unmanaged stands.

Estimating value of stands.--The values given in table 8 become even more meaningful when translated from volumes into dollars. An approximation of the relative value of timber stands on different sites was made by converting the volume and grade of the individual sawlog tree in the stand to a stumpage value. Three steps were included:

1. The number of trees in each diameter class, and their volumes, were taken from available stand tables and volume tables for different sites (15).

2. The average butt-log grade for trees in each diameter class was determined from the sample trees taken in this study.

3. Knowing the size and butt-log grade of a tree, its stumpage value was read directly from a table prepared for this purpose (4). This table, prepared by TVA foresters, is based on the value of factory-grade lumber.

Using this procedure, the relative stumpage value of sawlog material was determined (table 9). No stumpage value was applied to trees under profitable sawlog size (12 inches d.b.h.) since this comparison was made primarily to show the relationship between stand value and site index.

Table 9.--Relative stumpage value of sawlog material per acre at 100 years of age

(Without management)

Site index	Stumpage value
40	$ 0.34
50	1.77
60	15.70
70	56.70
80	140.64

It is interesting to compare table 9, which shows the stumpage value of sawlog material after logging costs, with table 8, which shows average board-foot volumes by site index. The increase in value with improved site quality is many times greater than the increase in volume alone would indicate.

Discussion Of Growth, Yield, & Value As Affected By Site Quality

It is recognized that yield-table values cannot be considered absolutely accurate in predicting the growth or value of any particular stand. They are based on plots measured only once and in the fully stocked portions of a forest area. For predicting actual values for any one area, they may be considerably in error.

The yield-table values were used here only to show the relative value of stands of different site-index classes. They are probably accurate enough to show that trend in growth and volume. So, although the stand values given in table 9 are based on averages only, they provide the timber owner or buyer and manager with a general yardstick for determining the relative value of a piece of property for producing sawtimber, once the site index is known. The values given should be considered only as rough approximations of the relative value of different sites. The actual conversion value of any stand under observation can be computed by using a similar approach that has been outlined by TVA foresters (4).

The difference in volume and value return for each site-index class is large enough that forest managers need to consider the inherent potential of the site for best results. Cutting cycles, intensity of management practices, road systems, and growing-stock levels need to be tailored to the potential productivity of the site (19).

Too little recognition of the variation in site in the past has led to the purchase of unproductive forest land. Also, investments have been put into sites that do not offer the best opportunity for producing a return on that investment in terms of added volume or value.

OTHER FACTORS MODIFY EFFECT OF SITE

Although the data show that the site quality of an area defines the limits within which management must operate, there are several natural factors that the forester can manipulate to influence growth and value.

FACTORS THAT INFLUENCE GROWTH

To measure the factors that affect diameter growth, increment cores were taken from individual trees. Growth during the last 10-year period was used to identify and measure the factors affecting growth of oak in the area. For only two species--northern red oak and chestnut oak--were there enough individual tree samples for complete testing of growth factors. Too few samples of the other oaks were taken to make valid comparisons.

Previous work (4, 10) indicates that tree vigor is related to diameter growth. Yield tables of oaks by Schnur (15) and McIntyre (12) show that site quality is also a major variable affecting volume growth of oak stands. The relationship of both site quality and tree vigor to the diameter growth of individual trees, however, has not been measured. In this study, the relative importance of each factor in determining growth was tested.

Tree vigor is a factor.--Analysis of northern red oak and chestnut oak diameter-growth data for the past 10 years showed each vigor class to be significantly different in growth rate (table 10). These figures are an average for the sites covered in this study. Better comparative figures are available in table 11, which relates vigor class and site index. The four vigor classes used (Appendix III) are shown in Figure 4.

Table 10.--Average d.b.h. growth in last 10 years for red oak and chestnut oak, by vigor class

(In inches, inside bark)

Vigor class	Northern red oak	Chestnut oak
I	2.63	1.81
II	1.93	1.46
III	1.18	.96
IV	.48	.64

Site quality a factor.--Diameter growth by tree-vigor class also varies by site quality. Regression analysis of diameter growth over site index showed that 10-year diameter growth of northern red oak is related to site quality for trees in Vigor Classes I and II, but not in Vigor Classes III and IV (Appendix IV). Average growth values of trees in Vigor III are slightly better on the better sites, but the difference is not statistically significant. Trees in Vigor Class IV show no correlation with site conditions. Apparently in these lower vigor classes suppression masks the effect of site difference.

The 10-year diameter growth of chestnut oak is related to site quality for trees in Vigor Classes I, II, and III, but not IV. Perhaps the greater tolerance of chestnut oak as compared to northern red oak minimized the effect of suppression in Vigor Class III to the extent that the influence of site factors could be statistically detected even though the effect of site on growth is slight. Table 11 gives the 10-year diameter growth of northern red oak and

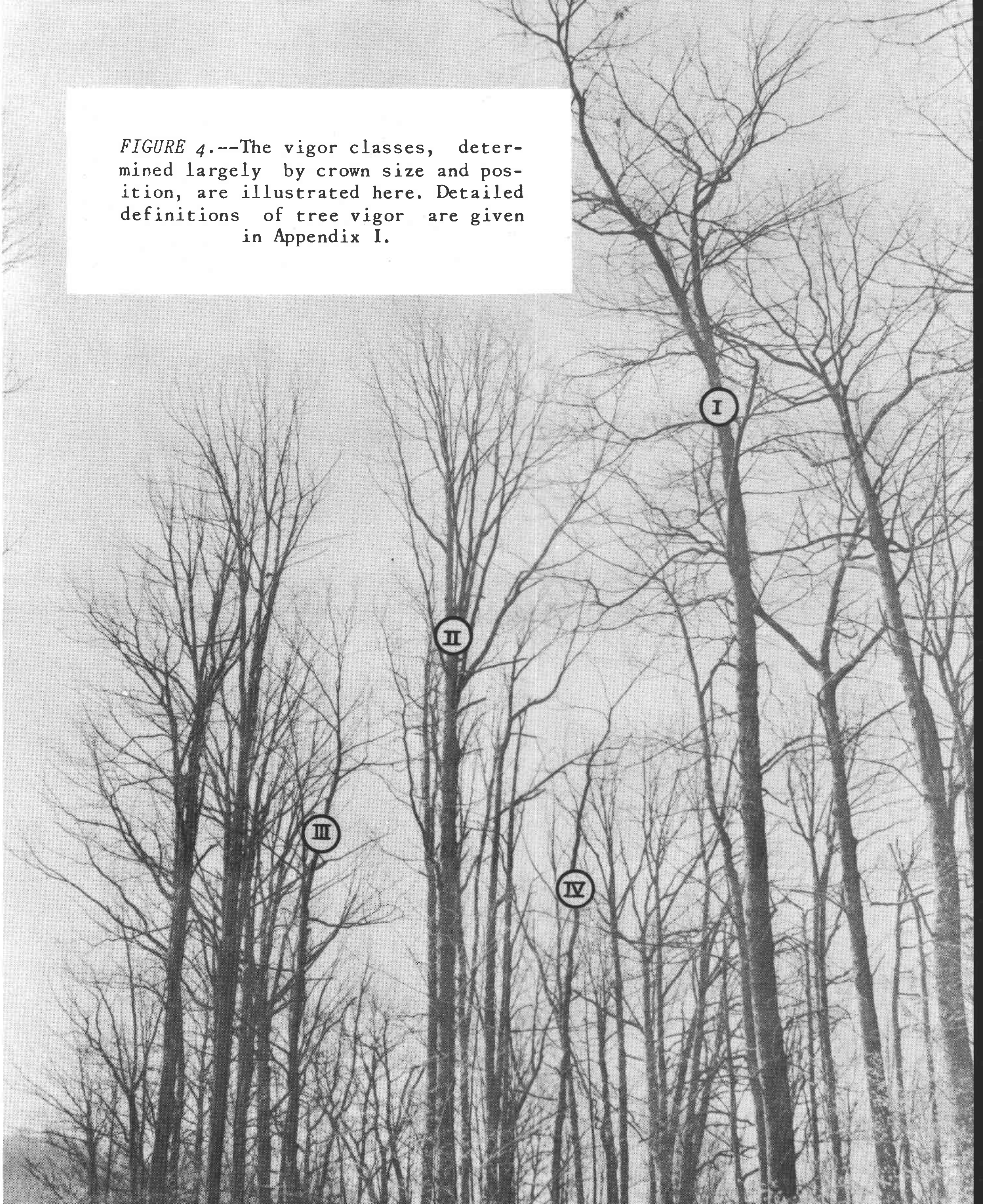

FIGURE 4.--The vigor classes, determined largely by crown size and position, are illustrated here. Detailed definitions of tree vigor are given in Appendix I.

chestnut oak by both vigor classes and site index.

Species is a factor.--The diameter-growth rates for northern red oak and chestnut oak were tested and proved to be significantly different (table 10). Northern red oak grows slightly faster under the same site and vigor conditions. Insufficient samples of the other oaks (black, white and scarlet) were available to permit analysis for difference in growth rates. Figure 12 shows the growth rates graphically for the two species by site index and vigor classes (Appendix IV).

Table 11.--Average d.b.h. growth for northern red oak and chestnut oak in last 10 years, by vigor class and site index

(In inches, inside bark)

Vigor class	Northern red oak at site index--					Chestnut oak at site index--				
	80	70	60	50	40	80	70	60	50	40
I	2.87	2.63	2.38	2.12	1.88	2.46	2.14	1.81	1.48	1.16
II	2.20	1.94	1.68	1.42	1.16	1.92	1.69	1.46	1.22	.99
III	1.19	1.18	1.18	1.17	1.16	1.07	1.02	.97	.92	.87
IV	.48	.48	.48	.48	.48	.64	.64	.64	.64	.64

Table 12.--Effect of tree size on d.b.h. growth of Vigor I northern red oak in last 10 years, by site-index classes

(In inches, inside bark)

Site index	D.b.h. (in inches)						
	10	12	14	16	18	20	22
80	3.27	3.11	2.95	2.79	2.63	2.48	2.32
70	2.91	2.76	2.60	2.44	2.28	2.13	1.97
60	2.56	2.40	2.25	2.09	1.93	1.77	1.62
50	2.21	2.05	1.89	1.74	1.58	1.42	1.26
40	1.86	1.70	1.54	1.38	1.23	1.07	.91

Tree size.--The effect of tree size on diameter growth of northern red oak was measured by regression analysis. The results of analysis indicate that tree size is a factor affecting diameter growth of trees in Vigor Class I only (Appendix IV). Diameter growth of Vigor I trees decreases as tree size increases. Table 12 shows this relationship. Yellow-poplar studies (10) showed a similar relationship. No significant growth differences could be detected for trees in Vigor Classes II, III, and IV. Trees in these vigor classes show a constant growth rate for each vigor class over the range of diameters studied. There was insufficient range in diameters of chestnut oak for testing for differences in growth due to tree size.

Discussion Of Factors That Influence Diameter Growth

For the two oaks tested, the most important factors in tree growth, operating within a species, are tree vigor and site quality. This relationship is a very logical one. Site quality indicates the amount and quality of nutrients and moisture available to the stand. Tree vigor indicates the relative amount the individual tree gets. A Vigor I tree is "hogging at the trough." If the meal is nutritious it grows faster than if it gets a less nourishing diet. On any site the disproportionate share enjoyed by the high-vigor tree results in faster growth than for its less vigorous neighbors in the same stand.

Site quality is most logically thought of in relation to the stand; vigor in relation to the individual trees. The practicing forester can do little to affect site quality; his realm of influence lies in modifying the environment of the individual tree (and indirectly its vigor). To successfully practice intensive forestry, he must know the potential growth limits of his sites. Then, within these broadly fixed limits, he manipulates the vigor-growth relationships of individual trees so as to follow the most profitable silvicultural practices.

Individual species apparently have a built-in growth potential. One species will grow faster than another when given the same opportunity. That northern red oak grows slightly faster than chestnut oak is probably a result of inherent growth characteristics over which forest managers have no control. However, the forest manager can control, to a certain extent, the species composition on a site.

ESTIMATING VOLUME GROWTH OF TREES

The growth data from cores were also used for estimating volume growth (tables 13 and 14). Since the practicing forester deals directly with volume, diameter growth by site-index class and tree-vigor class was converted to volume growth. Volume growth is affected by height growth as well as diameter growth. Thus these tables, which take height growth into account through site index, should be more meaningful to the forest manager than diameter growth alone.

The steps involved in converting diameter growth to volume growth are described in Appendix V. Briefly, they are: (1) Converting diameter growth inside bark to diameter growth outside bark: this puts growth figures on the conventional basis of growth at breast height outside bark. (2) Estimating diameter growth in next 10 years: growth in the future is more important in selecting trees to leave than growth in the past. (3) Converting future diameter growth to volume growth.

Table 13.--Estimated average volume growth for northern red oak trees in next 10 years, by vigor and site-index classes

(In board feet, International 1/8-inch rule)

Vigor class	Site index	D.b.h. (in inches)					
		10	12	14	16	18	20
I	80	59	70	82	94	104	111
	70	44	52	63	68	76	--
	60	33	38	44	52	57	--
	50	22	26	32	34	41	--
	40	16	18	--	--	--	--
II	80	44	50	61	69	78	102
	70	31	38	44	49	54	--
	60	22	27	30	36	40	--
	50	15	17	21	23	28	--
	40	9	11	12	--	--	--
III	80	20	23	29	32	38	41
	70	15	19	21	27	28	32
	60	13	16	18	21	24	26
	50	10	12	15	17	19	20
	40	8	9	10	--	--	--
IV	80	6	7	9	9	11	10
	70	4	5	6	8	8	9
	60	4	5	5	6	7	8
	50	3	4	4	5	6	6
	40	2	3	3	--	--	--

Table 14.--Estimated average volume growth for chestnut oak trees in next 10 years, by vigor and site-index classes

(In board feet, International 1/8-inch rule)

Vigor class	Site index	D.b.h. (in inches)					
		10	12	14	16	18	20
I	80	47	54	63	70	76	85
	70	33	38	45	49	55	61
	60	23	26	31	34	--	--
	50	14	16	20	--	--	--
	40	8	10	--	--	--	--
II	80	34	40	47	54	57	65
	70	26	30	36	38	44	48
	60	19	21	25	28	--	--
	50	12	14	17	--	--	--
	40	7	8	--	--	--	--
III	80	15	20	22	25	27	30
	70	12	15	17	20	23	25
	60	10	11	13	16	--	--
	50	6	9	11	--	--	--
	40	5	6	7	--	--	--
IV	80	8	10	11	13	14	16
	70	7	8	9	11	12	13
	60	6	6	8	9	--	--
	50	4	5	6	7	--	--
	40	3	4	5	--	--	--

FACTORS THAT INFLUENCE GRADE

The butt log of each sample tree was graded in accordance with U. S. Forest Products Laboratory grades for factory logs (18). Log grades were tallied so that they could be related to tree diameter breast high, site index, and tree age by species. Previous studies have shown a general relationship between butt-log grade and diameter (2, 4). The three new variables tested in this study were site index, tree age, and species.

One of the important variables known to affect grade --degree of stocking--was presumably held constant because grade samples were taken on reasonably well-stocked, even-aged stands undisturbed by cutting. However, it is probable that the relationship between grade and the factors tested was influenced by past differences in stand history and density.

Tree size.--Log-grade studies have shown a relationship between the size of the tree and the grade of the butt log (2, 4, 7). Since the grading rules themselves are partially based on size, it logically follows that larger trees have the potential of better grades. In our study the proportion of trees in the better grade classes increased rapidly with increasing d.b.h. For example, while chestnut oak trees 14 inches in diameter had an average butt-log grade of 3, practically all chestnut oaks over 20 inches d.b.h. had a grade 1 butt log. Trees damaged by insects, disease, fire, or wind are exceptions. A similar trend between d.b.h. and butt-log grade holds for northern red oak and white oak.

There is a standard deviation of approximately one-half a grade within a d.b.h. class. Though probably only valid for the stands sampled, the grade-d.b.h. relationships developed provide a measure of the inherent variation in grade by diameter for unmanaged stands.

Site-quality.--Butt-log grade appears to be independent of site quality for the oaks studied. Site affects log grade only to the extent that trees grow at different rates on areas of different site quality. To the extent that the growth rates on better sites are higher--and to that extent alone--is site index correlated with butt-log grades.

Age.--The greatest effect of age on grade is that within a site-index class and within a vigor class, the older the tree the greater the d.b.h. However, age also has an independent effect on log grade, which may be associated with healing of branch scars. Given two trees that are otherwise similar, the older will have a better butt-log grade on the average. For white and chestnut oak the effect of age is very small; for northern red oak, it is greater but still slight in over-all importance.

Species.--Tests were made to determine if butt-log grade differed by species. Red, white, and chestnut oak were tested. Analysis showed that both chestnut and white oaks clear at smaller diameters than red oak. Between chestnut and white oak no grade differences could be detected at any common size. In both white and chestnut oak, few trees larger than 20 inches d.b.h. were sampled. Scarlet oak gave a poorer butt-log grade than any of the other three oaks at all common diameters up to 20 inches d.b.h. Above this size, scarlet oak sample trees were unavailable for testing.

In this comparison between species, it should be made clear that the criterion is butt-log grade and not lumber grade. Butt-log grade is based on the external appearance of the log. The Forest Products Laboratory, in studies covering a number of species including white, chestnut, and northern red oak, has shown that the lumber grades obtained from butt logs of a given grade are not the same for all species (19).

Thus a No. 1 butt log of red oak produces a higher percentage of high-grade lumber than a No. 1 butt log of white or chestnut oak of the same diameter. It has also been shown that within a d.b.h. class the lumber conversion grades vary by species. Red oak, for example, produces a higher percentage of the better grades of lumber at 16 inches d.b.h. than white or chestnut oak. Thus butt-log grades alone cannot be used as an index of lumber grades when several species are compared. Reference must be made to tables of lumber grades by butt-log grades for each individual species.

Discussion Of Factors That Influence Grade

Results of this analysis indicate that there is a normal and inherent range in tree grades for any fixed diameter. A measure of this range can serve to indicate what grades one may reasonably expect--even in a managed stand. There is considerable talk about the "low-grade hardwood problem," as though it were something that could be solved through one swift gesture. From this study and forestry experience in Europe, where stands have been under management for hundreds of years, it appears that this "low-grade hardwood problem" will always remain with us. Apparently it is a result of the inherent variation in the grades within any one species and any one diameter class.

It therefore appears that management can improve grade in only two ways, excluding pruning and improvement through genetic selection from elite parents. One way is through the elimination of the lower grades within each diameter class through continuous improvement cutting; the other way is to push trees into larger diameters faster and thus encourage up-grading a little faster.

Log grades can also be used to determine the relative merits of leaving different trees in the stand to grow. Several tree-grade studies have pointed to the use of butt-log grade as a basis for economic guides to cutting (2, 4). Foresters have devised quality-index tables that permit an appraisal of the dollar value of any tree in the stand once the butt-log grade, diameter, and tree height are known (4, 9). In conjunction with estimates of growth and logging costs, this system provides a method for determining which tree to cut or leave.

Such economic appraisals offer excellent guides to profitable management. However, the present study would suggest that caution be exercised in applying any system of removing only profitable trees. If this concept were carried to an extreme, it could easily result in high-grading the forest by removing the best and most profitable trees with each cut and leaving the poorest for growing stock. Quality index provides a most useful tool for the forest manager when modified by the knowledge that some trees may always remain unprofitable because of poor grade and growth qualities. These must be removed for the sake of the future.

APPLYING THE RESEARCH DATA

A brief discussion of the silvicultural and management implications of the results followed each subject. Taken together, these discussions point out the practical applications that forest managers can make of the data.

MANAGE BY SITE INDEX

The data show that management of oaks must be adjusted to the site for best results. Economics demand it. The amount of money that can be invested in land and improvements is related to the ability of the site to produce a return on that investment. One of the errors of the past has been a failure to recognize differences in site productivity and to manage forest land accordingly. The volume and value of timber that can be grown per acre should be the yardstick for determining the amount of effort that can properly be put into management.

Yield tables that show the potential of the area may be used as rough guides. On poorer sites only the simplest improvements can be profitably made. Larger investments in cultural work can be made on better sites that have a higher growth potential, have better species, and can produce better grades at an earlier age. These sites offer an opportunity for larger and quicker returns on the investment. Better sites, therefore, call for more intensive management, higher growing-stock levels, and more frequent cuts.

SILVICULTURAL GUIDES

Under management, the silviculture that is practiced is, in the long run, strongly influenced by the site potential. The species composition, the ease in getting reproduction, and the number and size of trees in the final crop are all largely dependent on site quality.

On all sites, thinnings should be made as frequently as the productivity of the site permits. The inferior, defective, and mature trees should be cut. These thinnings will create favorable conditions for establishing oak seedlings by creating openings for overhead light. Large clear-cut areas are undesirable; they regenerate as sprout forests and on poor sites encourage the invasion of inferior species. On the other hand, single-tree selection that maintains constant shade on the area usually favors the more tolerant species. Thus a system of frequent cuts that create sufficient light to establish small even-aged groups of reproduction during the removal of mature trees is recommended.

In beginning management in many of today's defective stands, however, the first practical step is to make a conditioning cut. Here the elimination of worthless individual trees takes precedence over other measures to increase growth rate, establish reproduction, or improve species composition. For stands that are healthy enough so that more intensive management practices can be initiated, the data collected in this study supply some silvicultural guides.

One of the first aims of management is to build up a desirable growing stock of vigorous trees. . A knowledge of the relative growth of trees by vigor and species will aid the forest manager in deciding which trees to cut and which to reserve. In marking for improvement cuts or thinnings, the objective should be to develop Vigor I and II trees.

Larger trees can be grown more profitably on the better sites. It follows then that these are the sites best suited to growing sawtimber and veneer logs. On the poorer sites the objective should be the production of small tree products such as pulpwood.

In marking, those species that the study shows are best adapted to the site should be favored. There may be exceptions to this general rule because of high market values for certain species. However, great risk is often involved in trying to maintain species on sites where they are at a disadvantage in competition with species more suited to the area. Below are suggested guides to forest management for different sites:

<u>Site index 80 and above</u>.--The land in this class has the highest potential for growing forest crops. It will carry a relatively heavy capital investment in cultural measures and physical improvements.

Since growth rates are high, intensive management practices are economically desirable. This land class can carry a high growing-stock level--around 60 square feet of basal area in trees 10 inches d.b.h. and larger--without reducing annual growth of individual trees or risking a high mortality loss. After stands have been under management long enough for the culls to have been removed and a good diameter distribution to become established, they can be cut at frequent intervals--every 10 years or even more frequently.

These are moist sites and they provide suitable conditions for growing the more demanding hardwoods. Such species as yellow-poplar, black cherry, sugar maple, white ash, and basswood are common along with scattered excellent specimens of red oak and hickory (fig. 5).

Site index 70.--On the drier aspects--south, west, and southwest--this site group is found on the deep soils and gentle slopes; or, if the soils are shallow or the slopes steep, it is found only near the bottom of the slopes. On north and east aspects it is found on combinations of slope position, grade, and soil depth that are slightly less favorable than site class 80.

This class occurs on better-than-average forest areas. A mixture of the more demanding species often predominates, but the oaks--particularly red oak--form a pronounced component of the stand. This land can support a growing stock of around 50 square feet in trees 10 inches d.b.h. and over. Stands can be cut on a cycle of 15 to 20 years, and permanent road systems are likely to be a profitable investment, as are cultural measures.

Site index 60.--Most of this land is either steep or has shallow soils--in some cases, both. Oaks are the most numerous tree species, and scarlet and chestnut oak generally outnumber red oak. Black gum is frequently found here, while sassafras and black locust are often numerous in younger stands. Average unit values of the wood produced are low compared to the better sites that support higher value species (fig. 6).

Though these areas can grow good timber, longer rotations are necessary. Intensive cultural measures may not be profitable. These sites will support a growing stock of about 40 square feet (10 inches d.b.h. and larger) on a cutting cycle of 20 to 30 years.

Site index 50.--This is poor hardwood land. Logging may be profitable only for small products or on extremely long rotations. The low growth rate will permit little, if

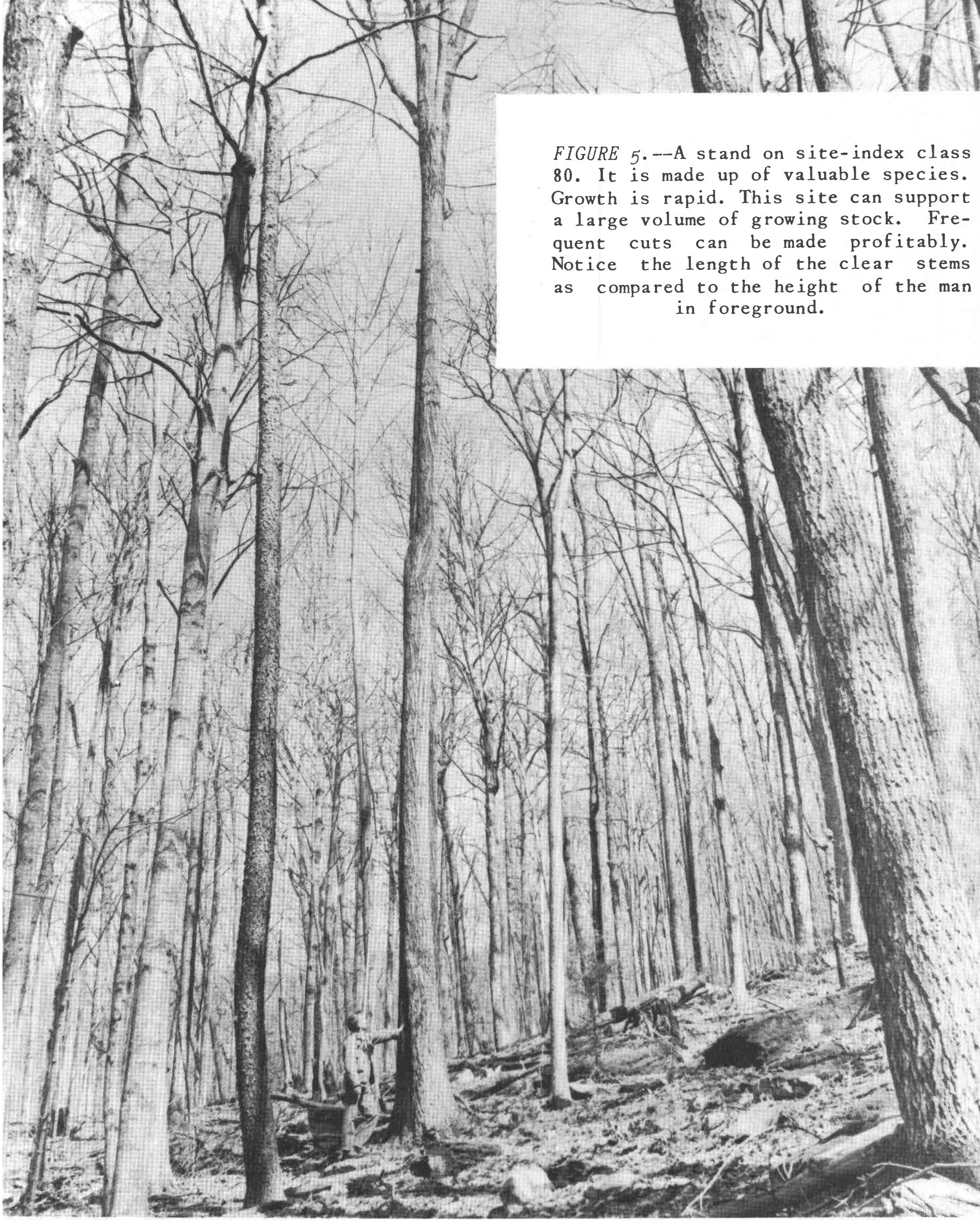

FIGURE 5.--A stand on site-index class 80. It is made up of valuable species. Growth is rapid. This site can support a large volume of growing stock. Frequent cuts can be made profitably. Notice the length of the clear stems as compared to the height of the man in foreground.

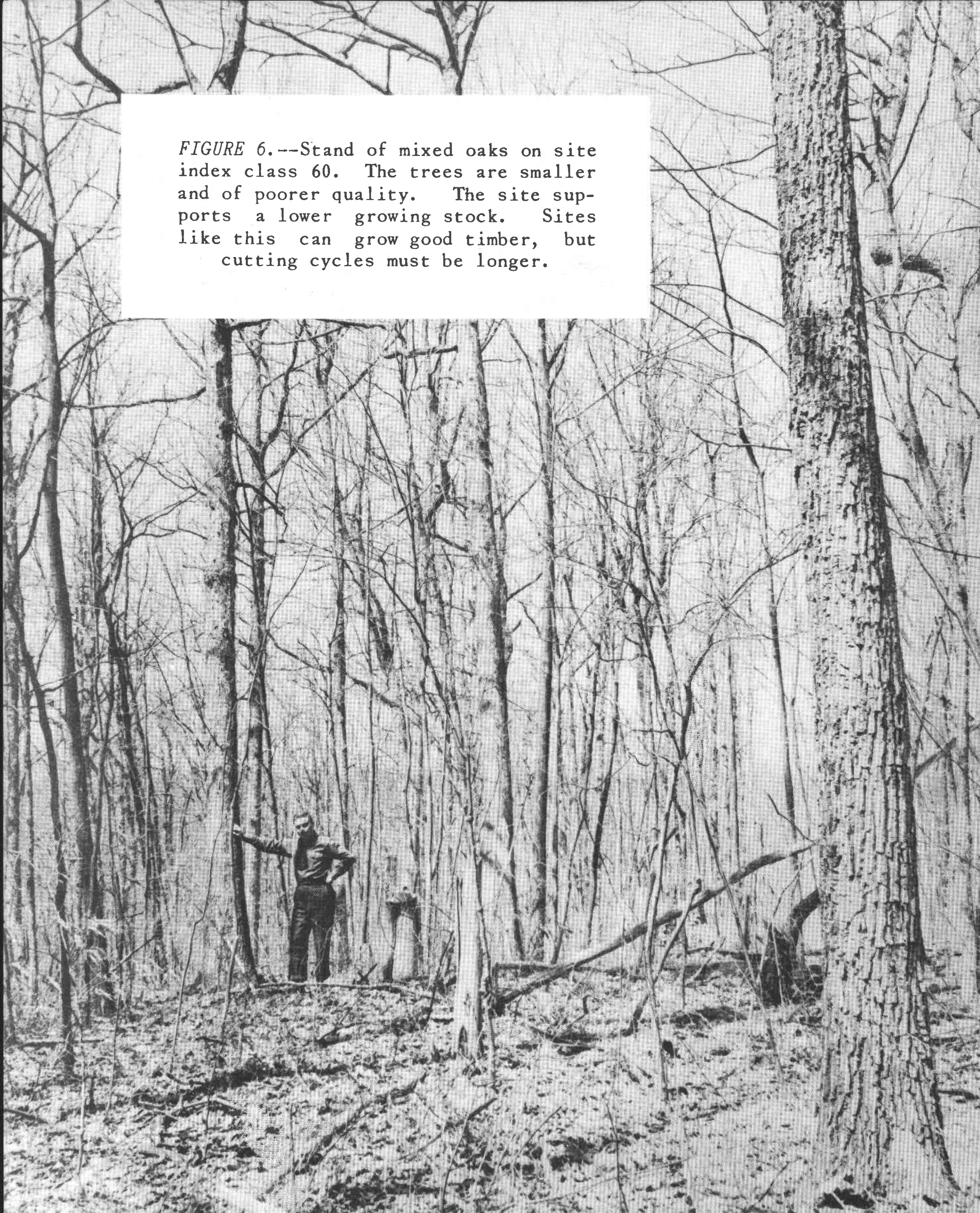

FIGURE 6.--Stand of mixed oaks on site index class 60. The trees are smaller and of poorer quality. The site supports a lower growing stock. Sites like this can grow good timber, but cutting cycles must be longer.

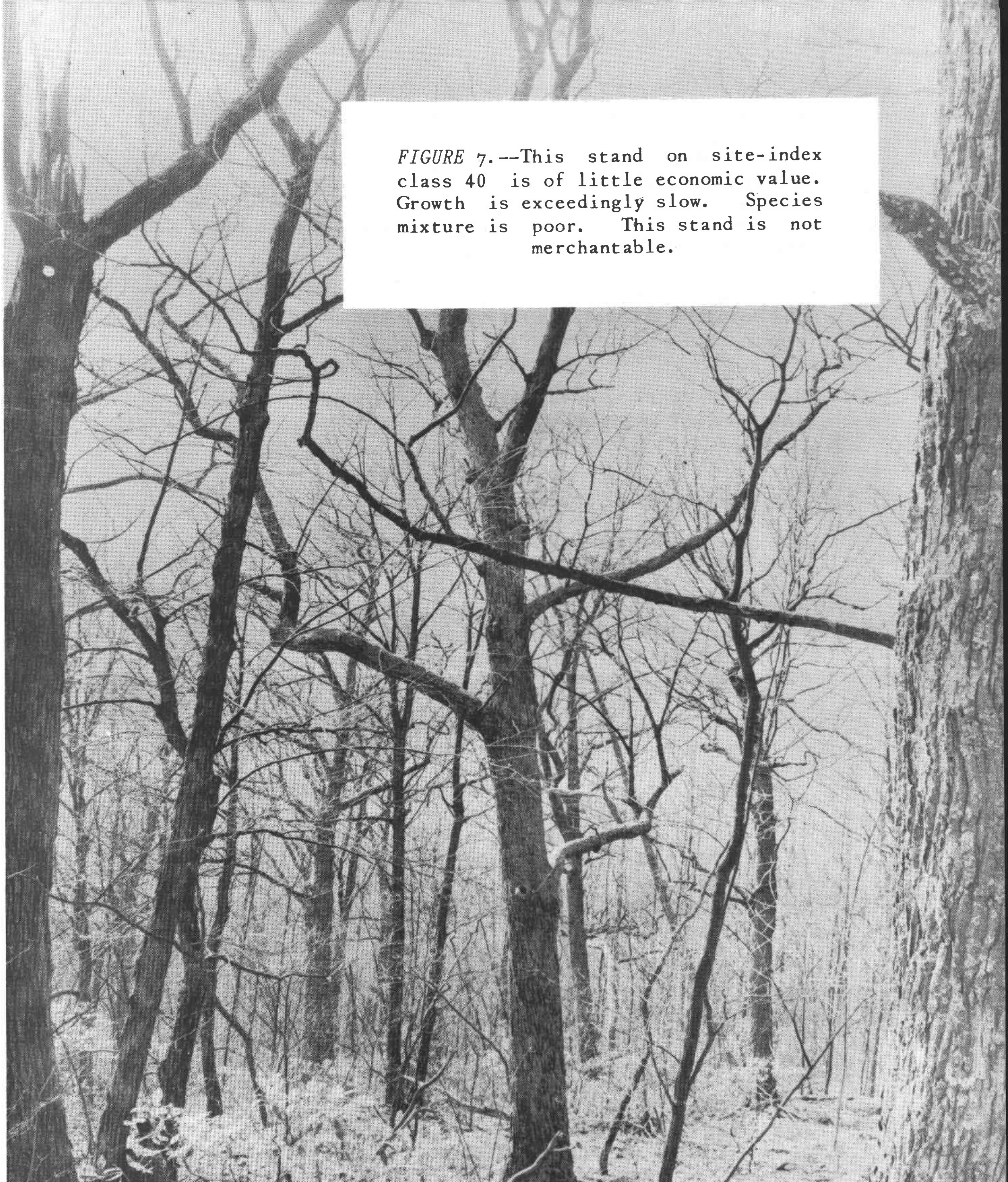

FIGURE 7.--This stand on site-index class 40 is of little economic value. Growth is exceedingly slow. Species mixture is poor. This stand is not merchantable.

any, investment in cultural measures.

The trees are of low value in both species and form. Scarlet oak, chestnut oak, black gum, and red maple are typical species. There are indications that some of the land in this class will profitably grow pine, but this needs further exploration.

Site index 40 and below.--This land is unsuited for the economic production of hardwood timber products. The growth rate is too low to pay the taxes (fig. 7).

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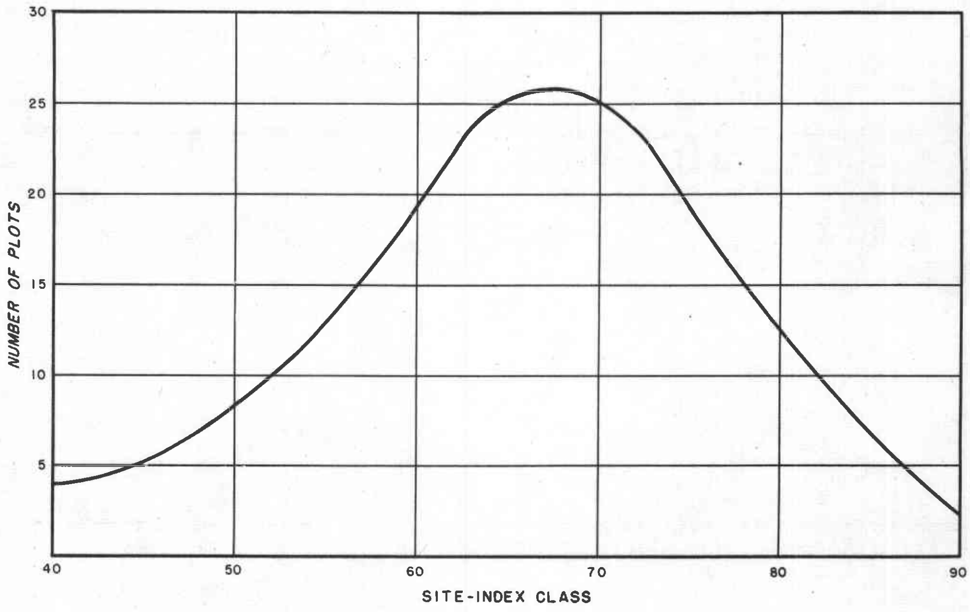
I

Site-index.--To determine the site index of a stand, a number (average 10 per plot) of dominant and co-dominant trees were sampled on 1/5-acre plots. Measurements were made of total height and total age of each sample tree. Reference was then made to a set of site-index curves (15) for oak. These curves showed total height over age for separate site-index classes. The site index of the stand was taken as an average of the site indexes of the sample trees.

FIGURE 8.--Distribution of sample plots by site-index classes.



To determine the factors that influence site quality, detailed measurements were made of a number of soil and land features on the plots. The soil data collected included humus type and depth, soil texture, depth of the root zone, total depth, and percent of stoniness. Data were also collected on aspect, topographic position, slope percent, and elevation.

Site index may be computed from the general formula:

$$Y = 1.9702 - 0.0618 X_1 + 0.0012 \cancel{X_3} X_2 - 0.0020 X_3 - 0.1509 X_4$$

where Y = site index as its logarithm to the base of 10; X_1 = the aspect as the sine of the azimuth taken clockwise from southeast and adding one; X_2 = the slope position as the percent distance from the ridgeline; X_3 = the grade as the percent slope; and X_4 = the total soil depth to bedrock as the reciprocal of soil depth in feet. Table 15 was derived from the formula.

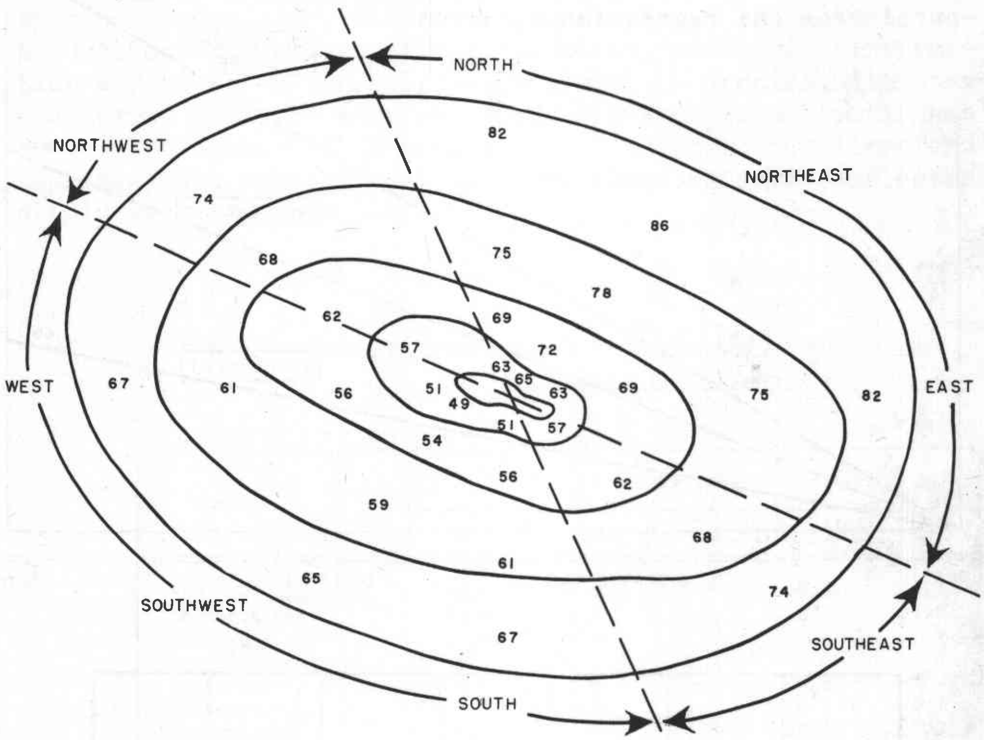
Although the site-index table gives the computed values for any combination of factors, figures 9, 10, and 11 give a graphic picture of the relative importance of each factor. Figure 9 gives the average site-index values around

Table 15.--Site index of oak as related to aspect, grade, and total soil depth[1]

Aspect	Total soil depth (feet)	Grade-percent				Grade-percent			
		10 or less	30	50	70	10 or less	30	50	70
		BOTTOM OF SLOPE				1/3 DISTANCE UP SLOPE			
NE	0.5	58	53	49	44	53	49	44	41
	1.0	83	76	69	63	76	69	63	57
	2.0	99	90	82	75	90	82	75	68
	3.0	104	95	87	79	95	87	79	72
NW-SE	0.5	50	46	42	38	46	42	39	35
	1.0	72	66	60	54	66	60	55	50
	2.0	85	78	71	65	78	71	65	59
	3.0	91	83	75	69	83	75	69	63
SW	0.5	44	40	37	33	40	37	33	30
	1.0	62	57	52	47	57	52	47	43
	2.0	74	68	62	56	68	62	56	51
	3.0	78	72	65	60	72	65	59	54
		2/3 DISTANCE UP SLOPE				UPPER SLOPE			
NE	0.5	49	44	41	37	45	41	37	34
	1.0	69	63	57	52	63	58	53	48
	2.0	82	74	68	62	75	69	63	57
	3.0	87	79	72	66	80	73	66	60
NW-SE	0.5	42	39	35	32	39	35	32	29
	1.0	60	55	50	45	55	50	46	42
	2.0	71	65	59	54	65	59	54	49
	3.0	75	69	63	57	69	63	57	52
SW	0.5	37	33	31	28	34	31	28	26
	1.0	52	47	43	39	46	43	40	36
	2.0	62	56	51	47	57	52	47	43
	3.0	65	60	54	50	60	55	50	45

[1] On poorly drained soils reduce table reading by 5 feet.

FIGURE 9.--Site index around a hill that has a 40-percent slope and 2 feet of soil. The values were computed from the regression equation.

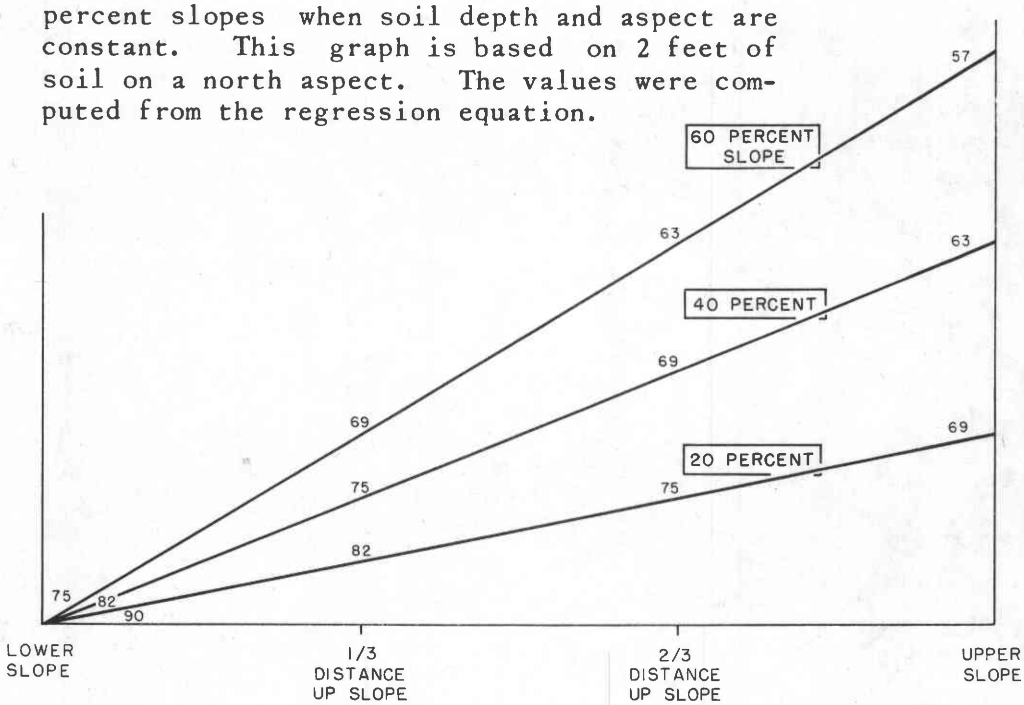


a hillside that has a soil depth of 2 feet and a slope of 40 percent. It demonstrates the relative importance of aspect and topographic position since soil depth and slope are constant. North and east slopes have sites about $1\frac{1}{2}$ site-index classes[4] higher than south and west slopes. All other things being equal, the oaks at the bottom of the slope will be about 2 site-index classes better than those at the top of the slope.

Figure 10 shows how site index changes as the slope percent is increased and decreased. Site index decreases about 3 feet with each 10 percent increase in slope of land. Figure 11 shows how site-index values change with soil depth. Notice how the site quality increases rapidly with increase in soil depth up to 2 feet. After that, the increase in site quality with an increase in soil depth is more gradual.

[4]Site-index values for oaks are normally grouped into 10-foot classes. Site index class 40 includes all site indexes from 35 to 44; site index class 50 includes site indexes from 45 to 54; and so on.

FIGURE 10.--Site index for 20-, 40-, and 60-percent slopes when soil depth and aspect are constant. This graph is based on 2 feet of soil on a north aspect. The values were computed from the regression equation.



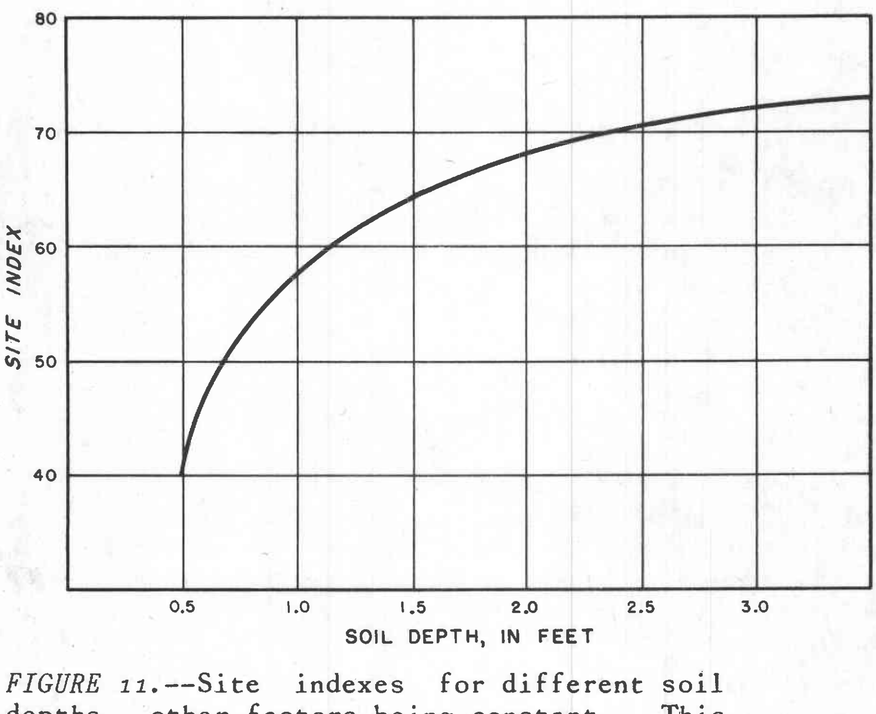


FIGURE 11.--Site indexes for different soil depths, other factors being constant. This graph is based on a 40-percent slope, a third of the distance from bottom to top, on southeast and northwest aspects. The values were computed from the regression equation.

II

Stand composition and structure.--To get a measure of species composition, diameter distribution, and natural reproduction within each site-index class, additional information was taken on these 1/5-acre plots. Species, diameter and crown position were recorded for each tree 5.0 inches d.b.h. and larger. Reproduction (including seedlings and saplings) was sampled on 5-milacre plots randomly selected within each 1/5-acre plot.

Table 16.--Number of trees per acre by species and site-index class (5.0 inches d.b.h. and over)

Species	Site index				
	40	50	60	70	80
Red oak	11.2	20.0	53.5	69.2	35.3
Chestnut oak	73.8	32.0	34.1	16.7	11.7
White oak	11.2	38.0	12.9	5.4	11.3
Scarlet & pin oak	2.5	40.0	18.5	4.4	1.3
Black oak	5.0	2.0	2.6	.8	--
Hickory	1.2	4.0	4.7	5.2	6.3
Red maple	6.5	1.0	18.8	17.3	9.3
Sugar maple	--	--	5.0	8.5	11.0
Yellow-poplar	--	--	2.6	10.6	16.7
Black cherry	--	--	5.9	11.7	14.7
Black birch	--	4.0	4.1	5.6	21.3
Black gum	--	3.0	1.8	1.0	.7
Cucumber	--	--	3.2	2.5	3.3
Sassafras	--	--	4.1	8.3	4.0
Beech	--	7.0	4.1	5.8	4.0
Hornbean	--	--	.3	.2	.3
White ash	1.2	--	1.2	4.2	3.7
Butternut	--	--	--	.6	.7
Sourwood	7.5	1.0	2.6	1.0	--
Yellow birch	6.2	--	.3	.4	1.0
White pine	--	3.0	--	--	--
Mountain magnolia	--	--	3.0	5.8	8.0
Moosewood	--	--	.6	.4	--
Ironwood	--	--	--	.2	--
Basswood	--	--	4.4	7.9	4.3
Serviceberry	--	--	.3	--	1.3
Dogwood	--	--	.6	.2	.3
Virginia pine	--	--	.3	--	--
Pin cherry	--	--	--	.2	.3
Hemlock	--	--	--	.6	3.3
Black locust	--	5.0	8.2	8.7	11.0
Pitch pine	--	1.0	--	--	--
Total	126.3	161.0	197.7	203.4	185.1
Number of plots	4	5	17	24	15

III

Since vigor class has been established (10) as an important factor in growth of individual trees, all diameter growth measurements were catalogued by vigor class as well as site-index class. The vigor of each sample tree was estimated and recorded before the increment borings were made to determine growth.

The vigor classifications that have been developed for different hardwoods differ somewhat in emphasis depending on the species. However, they are all based on size and shape of crown, bark characteristics, position in the stand and other minor features. The vigor classification of Holcomb and Bickford (10) was used as a guide, modified by the classifications of Cummings and Zarger (4) and Burkle and Guttenberg (1). The following four vigor classes were used:

Vigor I.--A tree in this vigor class has a large, healthy, full crown in a dominant or co-dominant position. Half the crown or more is exposed to direct sunlight. The crown is dense, with no evidence of disease or injury. Crown quality and position is 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, with some dead or broken limbs, or 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.

IV

Growth by site classes was one of the major variables to be tested. Radial growth of trees in all vigor classes, determined from borings, was converted to diameter growth for two periods: the growth for the last 10 years, and the growth for the last 20 years. These data, by species, were grouped by site-index classes.

Regression of diameter growth (inside bark) over site index for red oak and chestnut oak of different vigors fits the general equation:

$$Y = a + bx$$

where Y is growth in d.i.b. during last 10 years, a + b are constants, and x is site class. The growth equations:

Vigor class	For red oak	Vigor class	For chestnut oak
I	$Y = 0.90 + (0.026)x$	I	$Y = -0.146 + (0.033)x$
II	$Y = 0.124 + (0.026)x$	II	$Y = 0.052 + (0.023)x$
		III	$Y = 0.674 + (0.005)x$

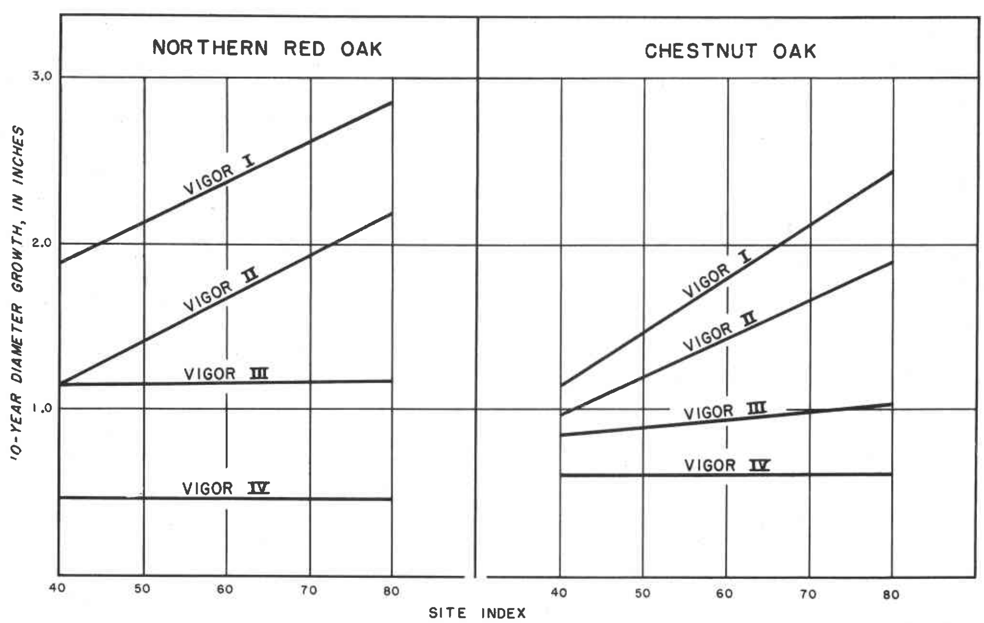


FIGURE 12.--Diameter growth of northern red oak and chestnut oak in the last 10 years, by vigor class and site index.

Tree size is a factor that affects diameter growth in Vigor I trees. The regression of diameter growth (i.b.) for northern red oak by site index and d.b.h. is expressed in the following equation:

$$Y = 1.2373 + (0.0352)\ x_1 - (0.0788)\ x_2$$

where Y is 10-year diameter growth (i.b.), x_1 is site index, and x_2 is d.b.h. Table 18 shows this relationship.

Correlation coefficient (R) = 0.89, which is significant at the 1-percent level as defined by Snedecor (16). The standard error of estimate is 4.8 percent.

V

The growth data from cores were also used for estimating volume growth. The following three steps were involved in converting diameter growth inside bark to board-foot volume growth.

1. Diameter growth inside bark was converted to diameter growth outside bark.--Growth in bark was added to the growth in wood. This put the growth figures on the conventional basis of growth at breast height outside bark. This was done by fitting a regression equation of bark thickness over diameter and getting the growth in bark for any unit of diameter growth. Separate bark-thickness curves were computed for northern red oak and for chestnut oak. These average bark-thickness curves were used to compute growth rates by species, vigor class, and site index--outside bark at breast height (table 17).

Regression of bark thickness over d.b.h. for northern red oak:

$$Y = 0.23 + 0.05x$$

Regression of bark thickness over d.b.h. for chestnut oak:

$$Y = 0.26 + 0.08x$$

in which Y = growth in bark and x is diameter breast high.

2. Determining diameter growth in next 10 years.--The data indicate that the diameter growth of individual trees in unmanaged stands will be slightly lower in the next decade than the average given in table 18 (which is the average for the past decade). Similar results were obtained in a growth study with yellow-poplar (10).

Table 17.--Average d.b.h. growth for northern red oak and chestnut oak, in last 10 years, by tree vigor and site index

(In inches, outside bark)

Vigor class	Northern red oak at site index--					Chestnut oak at site index--				
	80	70	60	50	40	80	70	60	50	40
I	3.05	2.80	2.53	2.26	2.20	2.70	2.35	1.98	1.62	1.27
II	2.34	2.06	1.79	1.51	1.23	2.10	1.85	1.60	1.34	1.09
III	1.27	1.26	1.25	1.24	1.23	1.17	1.12	1.06	1.01	.95
IV	.51	.51	.51	.51	.51	.70	.70	.70	.70	.70

Table 18.--Average d.b.h. growth of Vigor I northern red oak in last 10 years

(In inches, outside bark)

Site index	D.b.h. (in inches)						
	10	12	15	16	18	20	22
80	3.48	3.31	3.14	2.97	2.80	2.64	2.47
70	3.10	2.94	2.77	2.60	2.43	2.27	2.10
60	2.72	2.55	2.39	2.22	2.05	1.88	1.72
50	2.35	2.18	2.01	1.85	1.68	1.51	1.34
40	1.98	1.81	1.64	1.47	1.31	1.14	.97

Thus, if a forester is interested in estimating individual tree growth in the next 10 years in unmanaged stands, he should use the diameter-growth figures given in table 19. These values were obtained by averaging growth for the last 10 years and the previous 10 years by site index and vigor class, and determining a ratio between the two. This ratio was applied to the average growth figures obtained over the last 10 years; it approximates the expected growth during the next 10-year period.

Table 19.--Estimated d.b.h. growth for northern red oak and chestnut oak in next 10 years, by tree vigor and site index

(In inches, outside bark)

Vigor class	Northern red oak at site index--					Chestnut oak at site index--				
	80	70	60	50	40	80	70	60	50	40
I	2.44	2.24	2.02	1.81	1.60	2.16	1.88	1.58	1.30	1.02
II	1.87	1.65	1.43	1.21	.98	1.68	1.48	1.28	1.07	.87
III	.89	.89	.88	.87	.86	.82	.78	.74	.71	.66
IV	.26	.26	.26	.26	.26	.42	.42	.42	.42	.42

3. Converting future diameter growth to volume growth.--To estimate volume growth from the diameter-growth data, volume tables that consider merchantable height by diameter and site index are needed. Volume tables by Schnur (15) were used. Tables 13 and 14 give estimated volume growth in the next 10 years by vigor and site index. These growth estimates assume that there will be no change in the vigor during the next 10 years.

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