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Evaluating Oak Advance Reproduction In The Missouri Ozarks

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North Central Forest Experiment Station
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EVALUATING OAK ADVANCE REPRODUCTION IN THE MISSOURI OZARKS

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APPLICATION

This guide presents a method for determining in advance of final harvest whether reproduction is adequate to reasonably ensure the regeneration of an oak stand. The guide is based on studies of survival and growth of oak reproduction on a range of sites from site index 50 to 70 for black oak in the Missouri Ozarks. The guide assumes oaks will be grown in even-aged stands as recommended by Roach and Gingrich (1968) and Sander (1977).

The guide requires inventories of (a) the overstory and (b) the oak advance reproduction. Both inventories should be made at the same time and tallied on a form (fig. 1). If the oak advance reproduction inventory shows there are insufficient oaks to replace the stand, the overstory inventory is used to determine whether or not stump sprouts from overstory oaks are likely to be numerous enough to make up for deficiencies in advance reproduction.

To Use This Guide

1. Tally all oaks 1.6 inches d.b.h. and larger on 10 or more 1/20-acre plots by species and size classes (overstory inventory, see sample form (fig. 1)).

2. Determine average age of dominant and codominant oaks and site index from tables in Appendix II and record on the tally form. Also determine and record the average age of lower story (intermediate and suppressed) oaks that are 1.6 inches d.b.h. and larger.

3. Select the number of 1/735-acre plots (4.3 feet in radius) to use in the advance reproduction inventory from the following tabulation according to the acreage of the stand being examined:

For stand size (Acres)	Use this number of 1/735-acre plots
<10	25
10-30	40
30-50	60

4. Distribute these 1/735-acre plots uniformly throughout the stand.

5. Measure the tallest stem of advance oak reproduction on each 1/735-acre plot and record (advance reproduction inventory (fig. 1)). Tally these stems by 2-foot height classes and ½-inch ground diameter classes (table 1). A 6-inch caliper graduated in either tenth or quarter inches can be used for measuring ground diameters. Measure only trees 1.5 inches d.b.h. or less; stems larger than this should be considered part of the overstory and tallied as such, even if below the main canopy. If no oak advance reproduction is present, record zero for height and ground diameter on the tally form.

6. Record on the advance reproduction tally form the aspect of each plot by quadrant (NE, SE, SW, or NW) and its slope position (upper, middle, or lower thirds). For plots on level topography (all slopes less than 15 percent), narrow ridge tops, or bottoms, code as LE, RI, or BO, respectively, under slope position and use the stocking values for southeast/northwest aspects (table 1).

7. Determine the stocking value (SV) for each plot by referring to table 1 and record on the tally form. Then calculate the average SV and round off to the nearest whole number. If average SV is 30 percent or greater, oak advance reproduction is adequate; no further calculations are necessary and the stand can be harvested.

8. If the average SV is less than 30 percent, oak advance reproduction is inadequate to reproduce the stand if it is cut. But the stand can still be reproduced if enough stumps of the overstory oak trees will sprout after they are cut. To compute the contribution to reproduction stocking from expected stump sprouting:

a. Assume that the inventory of plots provides the data on the sample form (fig. 1).
b. Note that there are 26 black oaks 2 to 5 inches in diameter per acre. Multiply 26 by 0.42 (from table 2) to find how many of the 26 stumps are expected to produce codominant or dominant trees at age

Date 9/12/83 Compartment 1 Stand 10 Site Index 60

Stand Age(Dominants) 80 Stand Age(Lower story) 80

Overstory (1/20-acre plots)							Advance Reproduction (1/735-acre plots)					
Sample Point Number	D.B.H. Class	Black Oak	White Oak	Scarlet Oak	N. Red Oak	Other Spp.	Plot No.	Asp.	Slope Pos.	Ht.	Grnd. Dia.	SV
1	2-5	••	:•	•		••	1	SE	LO	0	0	0
	6-11		•			•	2	SE	LO	10	2.0	38
	12-16					•	3	SE	LO	0	0	0
	17+				•		4	SE	LO	2	.5	2
2	2-5	••	∷				5	SE	LO	2	.5	2
	6-11	•	•			••	6	SE	LO	0	0	0
	12-16		•				7	SE	LO	6	1.5	23
	17+						8	SE	LO	4	.5	4
3	2-5	•	•	••		•	9	SE	LO	8	1.5	28
	6-11			•			10	SE	LO	0	0	0
	12-16		•			•	11	SE	LO	6	.5	8
	17+						12	SE	LO	0	0	0
4	2-5		••			:•	13	SE	LO	2	.5	2
	6-11						14	SE	MI	4	.5	18
	12-16	••		•		••	15	SE	MI	8	1.5	73
	17+						16	SE	MI	4	.5	18
5	2-5		∷	••			17	SE	MI	8	1.5	73
	6-11	•	••				18	SE	MI	0	0	0
	12-16						19	SE	MI	4	1.0	37
	17+		•				20	SE	MI	1	—	2
6	2-5	•	••	:•		••	21	SE	MI	8	1.0	64
	6-11					•	22	SE	MI	0	0	0
	12-16	••	•			•	23	SE	MI	6	1.5	65
	17+						24	SE	MI	4	1.5	56
7	2-5	:•	:•	••			25	SE	MI	8	1.5	73
	6-11		•			••	26	SE	MI	0	0	0
	12-16					•	27	SE	UP	10	2.0	79
	17+	•					28	SE	UP	0	0	0
8	2-5	••	•	•	••	:•	29	SE	UP	0	0	0
	6-11	•					30	SE	UP	8	1.5	68
	12-16	•			•		31	SE	UP	1	—	1
	17+						32	SE	UP	10	2.0	79
9	2-5		:•			••	33	SE	UP	0	0	0
	6-11	•			•	•	34	SE	UP	0	0	0
	12-16	••	•	•		•	35	SE	UP	6	1.5	59
	17+						36	SE	UP	0	0	0
10	2-5	••	∷	•			37	SE	UP	0	0	0
	6-11		•		•	•	38	SE	UP	8	1.5	68
	12-16	••					39	SE	UP	6	1.5	59
	17+						40	SE	UP	1	—	1

	D.B.H. Class	Black Oak	White Oak	Scarlet Oak	N. Red Oak	Other Spp.	Total		
Total No. Per Acre	2-5	26	60	24	4	26	140	SV Mean	25
	6-11	8	12	2	4	22	48		
	12-16	18	8	4	2	14	46		
	17+	2	2	0	2	0	6		
	Total	54	82	30	12	62	240	Advance Reproduction Adequate?	No
No. of Stump Spts. Per Acre	2-5	11	11	11	2		Total Per Acre	Advance Reproduction + Stump Sprouts Adequate?	Yes
	6-11	1	1	2	2				
	12-16	1	0	2	1				
	17+	0	0	0	0				
	Total	13	12	15	5		45		

Figure 1.—*Example tally form for recording overstory trees and oak advance reproduction stocking and for computing the number of expected oak stump sprouts.*

Table 1.—*Stocking value*[1] *for advance reproduction inventory plots*

Size of tallest tree per plot: Height class (ft)	Size of tallest tree per plot: Ground diameter class	Southwest: Upper	Southwest: Middle	Southwest: Lower	Southeast & Northwest: Upper	Southeast & Northwest: Middle	Southeast & Northwest: Lower	Northeast: Upper	Northeast: Middle	Northeast: Lower
	In.	Plot Stocking Value (SV)								
≤ 1	All	1	1	0	1	2	0	1	1	0
2	0.5 (0.3-0.7)	5	6	1	8	9	2	4	5	1
(1.1-3.0)	1.0 (.8+)	14	17	3	22	26	6	13	15	3
4	0.5 (.3-.7)	10	11	2	15	18	4	8	10	2
(3.1-5.0)	1.0 (.8-1.2)	22	25	6	32	37	9	19	22	5
	1.5 (1.3+)	37	42	11	51	56	18	34	38	10
6	0.5 (.3-.7)	19	22	5	28	32	8	16	19	4
(5.1-7.0)	1.0 (.8-1.2)	32	36	9	45	50	14	29	33	8
	1.5 (1.3+)	45	50	15	59	65	23	41	46	13
8	1.0 (.8-1.2)	44	49	14	59	64	22	40	45	12
(7.1-9.0)	1.5 (1.3-1.7)	54	59	19	68	73	28	49	54	17
	2.0 (1.8+)	62	67	24	76	80	35	57	62	21
10+	1.0 (.8-1.2)	58	63	22	72	77	32	54	59	14
(9.1+)	1.5 (1.3-1.7)	62	67	24	76	81	35	58	63	16
	2.0 (1.8-2.2)	66	71	27	79	84	38	61	66	19
	2.5 (2.3+)	69	74	29	82	86	41	64	69	21

Narrow ridge tops ------------------------------------
Level areas (<15 percent slopes other than ridge tops and bottoms) -----
Bottoms ---

[1]Stocking Value (SV) is the contribution of a single stem to stand stocking at age 20.

20: 26 x 0.42 = 11 (rounded off to the nearest whole number). The expected number of stump sprouts per acre for 2- to 5-inch black oaks, 11, is listed at the bottom of figure 1.

c. Similarly, compute the expected number of stump sprouts for the other size classes of black oak (1 for the 6- to 11-inch class, 1 for the 12- to 16-inch class, and 0 for the 17+ inch class) and note that all these classes sum to 13. Do the same for all oak species.

d. Summing all oak species and all size classes gives a total of 45 expected stump sprouts per acre (fig. 1).

9. Go to table 3 and find the number of stump sprouts required in combination with advance reproduction stocking to meet minimum stocking requirements. Opposite 25 note that 37 stump sprouts are needed to make up the deficiency in advance reproduction. (Suppressed and intermediate oaks (particularly white oaks) may be younger than the stand dominants. Thus if 2- to 5-inch white oaks had been 40 years old instead of 80, expected stump sprouts from this diameter class would be 37 per acre—sufficient by themselves to compensate for the deficiency in advance reproduction. Consequently, the average age of lower story oaks should always be determined.)

10. Because the computed value (45) exceeds the tabulated value (37), oak stump sprouts will make up for deficiency in the advance reproduction. Thus, the oak component of the new stand will be adequate and the old stand can be harvested.

11. If the number of expected stump sprouts does not compensate for advance reproduction deficiencies, harvesting should be delayed until adequate oak advance reproduction is established. The alternative is to plant oak seedlings (Johnson [in prep.]).

12. To determine oak regeneration potential more rapidly, a program for Hewlett-Packard[1] programmable calculator is presented in Appendix III.

[1]*Mention of trade names does not constitute endorsement of the products by the USDA Forest Service.*

Table 2.—*Expected proportion of stumps that will produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20*

Species	Site index	D.b.h. class	Age of parent tree (years) 40	60	80	100	All ages
		In					
Black oak[1]	50	2-5	0.36	0.34	0.32	0.30	—
		6-11	.13	.11	.10	.08	—
		12-16	.06	.05	.04	.03	—
		17+	—	.02	.02	.01	—
	60	2-5	.47	.45	.42	.40	—
		6-11	.16	.15	.13	.12	—
		12-16	.07	.06	.05	.04	—
		17+	—	.03	.02	.02	—
	70	2-5	.61	.59	.56	.54	—
		6-11	.21	.19	.17	.16	—
		12-16	.10	.08	.07	.06	—
		17+	—	.05	.04	.03	—
White oak[1]	50	2-5	.47	.25	.12	.05	—
		6-11	.18	.10	.06	.03	—
		12-16	.06	.04	.03	.02	—
		17+	—	.02	.01	.01	—
	60	2-5	.63	.38	.19	.08	—
		6-11	.26	.16	.09	.05	—
		12-16	.09	.07	.05	.03	—
		17+	—	.03	.02	.02	—
	70	2-5	.81	.55	.31	.15	—
		6-11	.36	.25	.16	.09	—
		12-16	.15	.11	.08	.06	—
		17+	—	.05	.04	.04	—
Northern red oak[2]	60+	2-5	.86	.86	.49	.49	—
		6-11	.86	.86	.46	.46	—
		12-16	.86	.86	.38	.38	—
		17+	—	.86	.24	.24	—
Scarlet oak[3]	50+	2-5	—	—	—	—	0.46
		6-11	—	—	—	—	.96
		12-16	—	—	—	—	.46
		17+	—	—	—	—	.10

[1]Values are based on data from Johnson (1977).
[2]Values are based on data from Wendel (1975) and Johnson (1975).
[3]Values by parent tree age are not available. Values given are means for sawtimber-size stands of various but unknown ages.

Table 3.—*Number of stump sprouts required to compensate for stocking deficiencies of advance reproduction*

Mean stocking value (SV) for 1/735 - acre plots	Stump sprouts required
	Number per acre
≥30	0
29	8
28	15
27	23
26	30
25	37
24	45
23	52
22	59
21	67
20	74
19	81
18	89
17	96
16	103
15	111
14	118
13	125
12	133
11	140
10	148
9	155
8	162
7	170
6	177
5	184
4	192
3	199
2	206
1	214
0	221

DOCUMENTATION

Background

In even-aged stands, the oak component after final harvest cutting depends on size, number, and distribution of the oak advance reproduction (Sander 1971, 1972; Sander and Clark 1971). However, oak advance reproduction numbers differ greatly under mature stands. In the Missouri Ozarks, the number may range from less than 300 to more than 2,000 stems per acre.[2] Some of this variation is attributable to site quality—in general, oak advance reproduction is more abundant on average and poor sites than on good sites (Sander and Clark 1971).

Abundance of oak advance reproduction alone is not a good indicator of whether or not oaks will be a major component of a new stand after final harvest cutting. This is because much of the reproduction may be too small to successfully compete with associated vegetation. Thus, tree size, as well as tree numbers, should be considered in evaluating the oak regeneration potential.

Variation in oak advance reproduction size is related to recurrent stem dieback, which results in predominantly seedling-sprout populations in Ozark oak forests. Consequently, the root systems of large seedling-sprout reproduction are much older than the stems and are able to support much greater stem growth than recently established seedlings and small seedling-sprouts.

Both stem height and basal diameters of oak advance reproduction are related to growth after overstory removal (McQuilkin 1975, Sander 1971). Thus both height and diameter are indicators of total plant size and the potential of the root systems to support vigorous shoot growth after overstory removal.

Estimating fifth-year "success" probabilities.—To determine the relation between oak advance reproduction size and development after overstory removal, we measured 394 stems in 6 stands in the Missouri Ozarks before and after clearcutting. Eighty-five percent of these stems were black oak (*Quercus velutina* Lam.) and white oak (*Q. alba* L.) and the remainder were scarlet oak (*Q. coccinea* Muenchh.) and northern red oak (*Q. rubra* L.). These trees were well distributed across all aspects and slope positions in stands with black oak site index 50 to 70 (McQuilkin 1974).

We chose oak stump sprouts as the standard for determining oak reproduction success because of their rapid growth and predominance in the upper crown strata of these 5-year-old stands. We defined a "successful" oak as one that had attained at least 80 percent of the mean height of all oak stump sprouts measured. These stump sprouts averaged 11 feet tall at age 5 so to be "successful" an oak had to be at least 8.8 feet tall. Eighty percent was chosen as the success criterion because nearly all oaks at least 8.8 feet tall at age 5 were dominant or codominant. Using this criterion for success and initial and 5 year measurements, we developed equations for predicting the probability of success for an individual stem of a given size using logistic regression analysis (Engelman 1981). In addition to initial tree height and basal diameter, we used aspect and slope position to predict success probability (Appendix I). These success probabilities did not differ significantly by species ($P < 0.05$) so the resulting estimates are for all four species combined.

The regression estimates showed that success probabilities increase with increasing initial height and ground diameter. In addition, probabilities were highest on southeast and northwest aspects and on middle slope positions. Initial size being equal, probabilities of success were lowest on northeast facing slopes and on lower slope positions. Probabilities of success ranged from less than 0.01 for 1-foot tall trees of small diameter on lower slopes to 0.88 for trees 10 feet tall with large (2.5-inch) ground diameters on middle slopes of southeast or northwest aspects. In general these relations reflect a low likelihood of tree development in environments where soil moisture is extremely favorable or unfavorable. This relation may in turn be related to high mortality and/or poor growth on droughty sites and severe competition on moist sites.

Establishing A Future Stocking Goal

Determining the minimum amount of oak advance reproduction for adequate stocking in a new stand requires first defining "adequate stocking." At some future stage of stand development enough dominant and codominant oaks must be in the stand to furnish some minimum stocking level. The stage chosen for this guide is when the mean stand diameter is 3 inches. The goal we've selected is to have the stand at least 30 percent stocked (C level) with codominant and dominant oaks at this mean stand diameter. Total stand stocking will be higher because trees of other species and probably some smaller oaks will be present.

Unmanaged oak stands on average sites (black oak site index 60-75) in a Missouri study reached a mean stand diameter of 3 inches at age 20 to 25, and the dominant and codominant trees averaged 4.5 inches in diameter[2]. According to Gingrich's (1967) equation for defining minimum tree area requirements, one 4.5-inch tree contributes 0.136 percent stocking and requires 1.36 milacres of growing space. To attain the 30 percent stocking goal requires 30/0.136 or 221 trees averaging 4.5 inches in diameter when the mean stand diameter is 3 inches.

Estimating the Contribution of Advance Reproduction to Future Stand Stocking

Advance reproduction's contribution to future stand stocking depends on its future utilization of growing space. This is generally not practical to measure until the stand reaches a mean stand diameter of 3 inches—the lowest mean diameter shown on Gingrich's (1967) stocking chart. Because this occurs at about age 20, we extended fifth-year success probabilities (P5) to age 20 to estimate the advance reproduction contribution. We assumed a 1 percent per year loss of trees deemed successful the fifth year to mortality and suppression over the next 15 years (Sander *et al.* 1976). The resulting probabilities (P20) are thus estimates of the proportion of advance reproduction stems expected to be codominant or dominant at age 20.

Given these probabilities (P20), we then determined the number of oak advance reproduction stems (R) required to produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20 by using the following relation based on the binomial probability distribution:

$$R = \log(1-0.8)/\log(1-P20) \quad (1)$$

(Johnson 1976, Leak 1969). We selected 0.8 as a "confidence" probability because, it is a compromise between excessively high stocking requirements resulting from the use of a higher confidence probability on the one hand and an unacceptably low confidence in P20 on the other hand. The probability that *one* advance reproduction stem of a given size becomes codominant or larger 20 years after final harvest at least 80 percent of the time is then 1/R. Expressed as a percent, 1/R is referred to as a stocking value (SV) because it defines the contribution of a stem to future stand stocking and can be used to quantify the stocking of an individual plot.

The average stocking value for a stand based on an inventory using 1/735-acre plots is the percent of the 735 growing spaces expected to produce codominant or dominant oaks at a mean stand diameter of 3 inches (about age 20). This percent must then equal or exceed 30 (i.e., (221/735)100) for oak advance reproduction to be adequate and fulfill minimum future stocking requirements based on the 221 tree goal.

Sample Plot Size and Number

The appropriate unit for sampling oak advance reproduction should be related to the average size (4.5 inches d.b.h.) of dominant and codominant trees when the mean stand diameter is 3 inches. A 4.5-inch tree requires 1.36 milacres or 1/735-acre of growing space. Theoretically, then, on any given acre the opportunity exists for each 1/735-acre to contain one 4.5-inch tree. At or beyond a mean stand diameter of 3 inches, more than one codominant or larger tree would not be expected to persist within this sample space. Thus the appropriate plot size is 1/735-acre (4.3-feet radius).

The number of 1/735-acre plots shown on page one is a reasonable estimate of the minimum number of sample plots needed for inventorying advance reproduction. If greater precision is desired, a preliminary sample should be used to estimate confidence limits and the required number of plots for a given level of precision should be calculated based on the binomial distribution (Freese 1962).

THE ROLE OF STUMP SPROUTS

The potential for sprouting from stumps of overstory oaks can be used to compensate for deficiencies in oak advance reproduction when evaluating the oak reproduction potential of a stand. Stump sprouts are the fastest growing oak component in new stands and those of low origin generally develop into good quality trees.

Factors shown to influence oak stump sprouting in a Missouri study include parent tree age and d.b.h. and site quality. Sprouting frequency decreases with both increasing parent tree age and d.b.h. but increases with increasing site quality. These relations were used to develop equations to estimate the proportion of parent trees that would produce codominant or larger black, white, and scarlet oaks at age 5 (Johnson 1977). These proportions were adjusted for anticipated mortality to stand age 20 by assuming a population reduction of 0.75 percent per year for 15 years. This adjustment was based on a 32-year stump sprout study (Roth and Hepting 1969). Data from Wendel (1975) and Johnson (1975) were similarly used to estimate proportions for northern red oak.

Using these adjusted proportions, values of R were calculated by using equation (1); 1/R was then used as the estimate of the proportion of parent trees expected to produce, at probability 0.8 or greater, at least one codominant or larger stem at age 20 (table 2). For black oak and white oak, expected proportions are shown by parent tree age, parent tree d.b.h., and site index. Age and site index information were not available for scarlet oak, so proportions are given by diameter classes only. The latter values are averages for sawtimber-size stands in the Missouri Ozarks. Proportions for northern red oak are based on data from parent stands in West Virginia that were 50- to 55-years-old on site index 60 to 80, and from stands in Wisconsin that ranged from about 70- to 110-years-old on site index 50 to 70 (Wendel 1975, Johnson 1975). Season of cutting may also influence stump sprouting and subsequent sprout development (Wendel 1975, Clark and Liming 1953), so we took this into account when determing these probabilities.

The minimum number of stump sprouts per acre (N) required to compensate for deficiencies in advance reproduction is:

$$N = 221 - \overline{SV}(7.35),$$

where $\overline{SV}$ is the mean stocking value for oak advance reproduction obtained by applying stocking values for advance reproduction inventory plots (table 1) to an inventory of 1/735-acre plots (table 3). This minimum number of trees can then be compared to the estimated number of expected stump sprouts to determine if advance reproduction plus stump sprouts will be adequate to replace the old stand.

IN CONCLUSION

The guide presents a method for obtaining "best available" estimates of the regeneration potential for Ozark oak forests based on currently available information. How well the guide works can be determined only by how many oaks grow fast enough to maintain themselves in a good competitive position as the stand develops. We used data from six Missouri Ozark stands to make a small test of the guide's ability to predict "success." Based on the number of oaks per acre at least 8 feet tall at age 5 the guide predicted "success" correctly in 5 of the 6 stands.

We hope silviculturists will apply the guide conscientiously and test its validity by inventorying reproduction at periodic intervals after harvest cutting. We hope users will share their results with us. In this way we can be made aware of the guide's shortcomings or strengths and what revisions may be needed. It will be revised as experience in application and new information dictates.

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APPENDIX I.

Regression coefficients for the equation for estimating fifth-year success probabilities (P5) for oak advance reproduction[1]

Independent variable	Regression coefficient (B)[2]
X1: Square root of tree ground diameter (in)	5.10
X2: Total tree height (ft)	0.700
X3: X1 x X2	-0.444
X4: Log(success criterion)[3]	-5.95
X5: Aspect(V1)[4]	-0.284
X6: Aspect(V2)[4]	0.404
X7: Slope position(V1)[5]	-1.10
X8: Slope position(V2)[5]	0.646
Constant (B_0)	19.0

[1]The equation is of the form:

$$P5 = 1 + \exp[-B_0 + B_1X_1 + \ldots B_nX_n)]^{-1},$$

where P5 is the probability that an individual stem of oak advance reproduction will attain or exceed the success criterion set by the value of X4.

[2]All regression coefficients are significant at the 0.01 level. Goodness of fit was also evaluated by chi-square (Engelman 1981). Total number of observations in the regression data set was 2,364.

[3]X4 = the natural logarithm of the selected success criterion (a percent). We solved the equation for a success criterion of 80, i.e., 80 percent of mean stump sprout height at age 5. At that age stump sprouts averaged 11 feet tall, and those that were 80 percent or more of that height (i.e., at least 8.8 feet tall) were usually codominant or dominant and thus "successful". However, the equation can be solved for any success criterion (e.g., 70 or 90 percent).

[4]X5 and X6 are vectors (V) of the independent variable "aspect" that *jointly* express the aspect effect on the estimate of P5. Coded values of X for both vectors are given below for the four aspects considered.

Aspect	Value of X for vector Aspect(V1)	Aspect(V2)
SW	-1	-1
SE and NW	0	1
NE	1	0

[5]X7 and X8 are vectors (V) of the independent variable "slope position" that *jointly* express the slope position effect on the estimate P5. Coded values of X for both vectors are given below for the three slope positions considered.

Slope position	Value for X for vector Slope position(V1)	Slope position(V2)
Upper third	-1	-1
Middle third	0	1
Lower third	1	0

To simplify application, we used categorical values of aspect and slope position instead of continuous values such as degrees azimuth and percent of distance from the ridge. The values of these categorical variables are based on "effects" coding and are generated by the logistic regression program (Engleman 1981); the statistical properties of the resulting coefficients are discussed by Kerlinger and Pedhazur (1973, pp. 121-128).

APPENDIX II.— Determining Site Index

1. Select at least 5, preferably 10, straight undamaged dominant or codominant trees per stand that show no signs of suppression. Selected trees should not differ more than 5 years in age from the trees immediately surrounding them.
2. Measure tree height and breast-height age; add 2 years to breast-height age to get total age.
3. Calculate average height and age and look up site index in tables 4 and 5.
4. Approximate conversions between species may be made as follows:
   Black oak SI = Scarlet oak SI-3
   Black oak SI = White oak SI+4
   Scarlet oak SI = Black oak SI+3
   White oak SI = Black oak SI-4.

Table 4.--*Black and scarlet oak site index estimates by 2-foot height and 2-year age intervals*1/ *(McQuilkin 1974)*

Age (years)	8	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
10		55	57	59	61	63	64	66	68	70	72																																
12			54	56	58	60	62	63	65	67	69	71																															
14				53	55	57	59	61	62	64	66	68	70	72	74																												
16					52	54	56	58	60	62	63	65	67	69	71	73	75																										
18						51	53	55	57	59	60	62	64	66	68	70	72	74	76	78																							
20							50	52	54	56	58	60	61	63	65	67	69	71	73	75	77	79																					
22								49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																					
24									48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																			
26										48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78																		
28										45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	76																		
30											45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77																
32												45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77															
34													45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77														
36													42	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	78													
38														42	44	47	49	51	53	55	57	59	61	63	65	67	69	71	74	76	78												
40															42	44	47	49	51	53	55	57	59	61	63	65	67	70	72	74	76	78											
42																43	45	47	49	51	54	56	58	60	62	64	66	68	70	72	74	76	78	80									
44																	44	46	48	50	52	54	56	58	60	62	64	67	69	71	73	75	77	79	81								
46																	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81							
48																		43	45	47	49	51	53	55	57	59	61	64	66	68	70	72	74	76	78	80	82						
50																			44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82					
52																				45	47	49	51	53	55	57	59	61	63	65	67	69	71	73	75	77	79	81					
54																				44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	75	77	79	81				
56																				43	45	47	49	51	53	55	57	59	61	63	65	67	68	70	72	74	76	78	80				
58																					44	46	48	50	52	54	56	58	60	62	63	65	67	69	71	73	75	77	79	81			
60																					44	45	47	49	51	53	55	57	59	60	62	64	66	68	70	72	74	75	77	79			
62																					43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71	73	74	76	78	80		
64																					42	44	46	48	50	51	53	55	57	59	61	62	64	66	68	70	71	73	75	77	79		
66																						43	45	47	49	51	52	54	56	58	60	61	63	65	67	69	70	72	74	76	78	79	
68																						43	45	46	48	50	52	53	55	57	59	61	62	64	66	68	69	71	73	75	76	78	
70																						42	44	46	47	49	51	53	54	56	58	60	61	63	65	67	68	70	72	74	75	77	78
72																						42	44	46	47	49	51	52	54	56	57	59	61	62	64	66	68	69	71	73	74	76	78
74																							44	45	47	49	50	52	54	55	57	59	60	62	64	65	67	68	70	72	73	75	77
76																							43	45	47	48	50	52	53	55	56	58	60	61	63	64	66	68	69	71	73	74	76
78																								45	46	48	50	51	53	54	56	58	59	61	62	64	65	67	69	70	72	73	75
80																								45	46	48	49	51	52	54	55	57	59	60	62	63	65	66	68	69	71	72	74

1/ All height and age combinations in this table are within the range of the original black oak data; height and age combinations within the lines indicate the range of the original scarlet oak data.

Table 5.--*White oak site index estimates by 2-foot height and 2-year age intervals*[1/] *(McQuilkin 1974)*

Age	Height (feet)																																								
(years)	10	12	14	16	18	20	22	24	26	28	30	32	34	36	38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70	72	74	76	78	80	82	84	86	88	90	92
10	46	49	52	54	57	60	62	65	68																																	
12	44	47	49	52	54	57	60	62	65	68																																
14		44	47	49	52	54	57	59	62	64	67	69																														
16			44	47	49	52	54	56	59	61	64	66	68	71																												
18				44	47	49	51	54	56	58	61	63	65	68	70																											
20					44	46	48	51	53	55	57	60	62	64	66	69																										
22					42	44	46	48	51	53	55	57	60	62	64	66	69	71																								
24						42	44	46	48	51	53	55	57	59	62	64	66	68	71																							
26							42	44	46	48	51	53	55	57	59	62	64	66	68	70																						
28								42	44	46	48	50	53	55	57	59	61	64	66	68	70																					
30									42	44	46	48	50	52	55	57	59	61	63	66	68	70																				
32									40	42	44	46	48	51	53	55	57	59	61	64	66	68	70																			
34										40	42	44	46	49	51	53	55	57	59	62	64	66	68	70																		
36											40	42	45	47	49	51	53	55	57	60	62	64	66	68	70																	
38												40	43	45	47	49	51	53	55	57	60	62	64	66	68	70																
40													41	43	45	47	49	51	53	55	58	60	62	64	66	68	70															
42													39	41	44	46	48	50	52	54	56	58	60	62	64	66	68	71														
44														40	42	44	46	48	50	52	54	57	59	61	63	65	67	69	71													
46														39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71												
48															39	41	43	45	47	49	52	54	56	58	60	62	64	66	68	70												
50															38	40	42	44	46	48	50	52	54	56	58	60	62	64	66	68	70											
52																39	41	43	45	47	49	51	53	55	57	59	61	63	65	67	69	71										
54																	40	42	44	46	48	50	52	54	56	58	60	62	63	65	67	69	71									
56																	39	41	43	45	47	49	51	53	55	56	58	60	62	64	66	68	70									
58																		40	42	44	46	48	50	51	53	55	57	59	61	63	65	67	68	70								
60																		39	41	43	45	47	48	50	52	54	56	58	60	61	63	65	67	69	71							
62																			41	42	44	46	48	49	51	53	55	57	58	60	62	64	66	67	69	71						
64																			40	42	43	45	47	49	50	52	54	56	57	59	61	62	64	66	68	69	71					
66																			39	41	43	44	46	48	49	51	53	54	56	58	59	61	63	64	66	68	70					
68																			39	40	42	44	45	47	49	50	52	54	55	57	58	60	61	63	65	66	68	69				
70																				40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	64	65	66	68	69			
72																				39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70		
74																				39	40	42	43	45	47	48	50	51	53	54	56	57	59	61	62	64	65	67	68	70		
76																					40	41	43	45	46	48	49	51	52	54	55	57	58	60	62	63	65	66	68	69	71	
78																					39	41	42	44	46	47	49	50	52	53	55	56	58	59	61	63	64	66	67	69	70	
80																					39	40	42	43	45	47	48	50	51	53	54	56	57	59	60	62	64	65	67	68	70	71

[1/] All height and age combinations to the left of the line are within the range of the original data; combinations to the right of the line are extrapolations.

APPENDIX III

OAKREGEN: HP41C, a program for computing average stocking value and expected stump sprouting. This 1862 byte program can be run only on a Hewlett-Packard HP41CV or an HP41C with four memory modules added. A printer is desirable but not neccessary. Clear the calculator of all programs, reserve 51 registers for data by pressing the following keys [XEQ] [ALPHA] SIZE [ALPHA] 051, and then key in the OAKREGEN program listed below.

HOW TO USE THE PROGRAM

A. To determine if advance reproduction alone is adequate press [XEQ] [ALPHA] AR [ALPHA] and you will be prompted to enter advance reproduction data. Press [R/S] after you enter each number. Use the following codes for aspect and slope position:

ASPECT	CODE	SLOPE POSITION	CODE
SW	1	Upper	1
SE & NW	2	Middle	2
NE	3	Lower	3

If there are no trees on a plot, press [R/S] when prompted for aspect.

After all data has been entered, calculate average stocking value by pressing [XEQ] [ALPHA] SV [ALPHA].

B. To determine the contribution of stump sprouts to future stocking press [XEQ] [ALPHA] OV [ALPHA] and enter overstory data when prompted. Press [R/S] after entering each number. After all data has been entered, calculate the number of stump sprouts expected per acre by pressing [XEQ] [ALPHA] ST [ALPHA].

```
01♦LBL "OV"
02♦LBL 01
03 FIX 3
04 0
05 0.01601
06 STO 50
07♦LBL 03
08 0
09 STO IND 50
10 ISG 50
11 GTO 03
12 STO 48
13 "PLOT SIZE? "
14 PROMPT
15 STO 17
16 ARCL 17
17 AVIEW
18 FIX 0
19 "STAND AGE? "
20 PROMPT
21 STO 18
22 ARCL 18
23 AVIEW
24 "SITE INDEX? "
25 PROMPT
26 STO 19
27 ARCL 19
28 AVIEW
29 ADV
30♦LBL 02
31 ADV
32 1.01601
33 STO 50
34 1
35 ST+ 00
36 RCL 00
37 "POINT=
38 ARCL 00
39 AVIEW
40 0
41 "BO 2-5? "
42 XEQ 90
43 "BO 6-11? "
44 XEQ 90
45 "BO 12-16? "
46 XEQ 90
47 "BO 17+? "
48 XEQ 90
49 "WO 2-5? "
50 XEQ 90
51 "WO 6-11? "
52 XEQ 90
53 "WO 12-16? "
54 XEQ 90
55 "WO 17+? "
56 XEQ 90
57 "SO 2-5? "
58 XEQ 90
59 "SO 6-11? "
60 XEQ 90
61 "SO 12-16?"
62 XEQ 90
63 "SO 17+? "
64 XEQ 90
65 "RO 2-5? "
66 XEQ 90
67 "RO 6-12? "
68 XEQ 90
69 "RO 12-16? "
70 XEQ 90
71 "RO 17+? "
72 XEQ 90
73♦LBL 90
74 PROMPT
75 ARCL X
76 AVIEW
77 ST+ IND 50
78 0
79 ISG 50
80 RTN
81 GTO 02
82♦LBL "ST"
83 RCL 00
84 1
85 -
86 STO 00
87 "**************"
88 AVIEW
89 ADV
90 "STUMPS PER ACRE"
91 AVIEW
92 "BO.WO.SO.RO."
93 AVIEW
94 CLA
95 1.01304
96 "2-5: "
97 XEQ 05
98 2.01404
99 "6-11: "
100 XEQ 05
101 3.01504
102 "12-16: "
103 XEQ 05
104 4.01604
105 "17+: "
106 XEQ 05
107 1.01701
108 STO 50
109 6.00901
110 STO 49
111♦LBL 10
112 3.5
113 XEQ IND 49
114 ISG 50
115 CLD
116 8.5
117 XEQ IND 49
118 ISG 50
119 14
120 XEQ IND 49
121 ISG 50
122 19.5
123 XEQ IND 49
124 ISG 50
125 ISG 49
126 GTO 10
127 CLA
128 ADV
129 "SPROUTS PER AC."
130 AVIEW
131 "BO.WO.SO.RO."
132 AVIEW
133 1.01304
134 "2-5: "
135 XEQ 56
136 2.01404
137 "6-11: "
138 XEQ 56
139 3.01504
140 "12-16: "
141 XEQ 56
142 4.01604
143 "17+: "
144 XEQ 56
145 ADV
146 "TOTAL SPROUTS= "
147 "├ "
148 ARCL 48
149 AVIEW
150 STOP
151♦LBL "AR"
152 0
153 STO 31
154 ADV
155 "ADV REP"
156 AVIEW
157 0
158 STO 22
159♦LBL 11
160 1
161 ST+ 22
162♦LBL 39
163 "PLOT= "
164 ARCL 22
165 AVIEW
166 23.02601
167 STO 50
168 "ASPECT? "
169 SF 01
170 0
171 XEQ 95
172 "SLOPE? "
173 0
174 XEQ 95
175 "HEIGHT? "
176 .5
177 FIX 1
178 SF 00
179 XEQ 95
180 0
181 "DIA? "
182 .2
183 SF 02
184 XEQ 95
185 FIX 0
186 RCL 23
187 1
188 X=Y?
189 GTO 12
190 RCL 23
191 2
192 X=Y?
193 GTO 13
194 RCL 23
195 3
196 X=Y?
197 GTO 14
198♦LBL 38
199 "BAD ENTRY"
200 AVIEW
201 GTO 39
202♦LBL 18
203 RCL 24
204 1
205 X=Y?
206 GTO 15
207 RCL 24
208 2
```

```
209 X=Y?
210 GTO 16
211 RCL 24
212 3
213 X=Y?
214 GTO 17
215 GTO 38
216♦LBL 19
217 RCL 26
218 SQRT
219 5.1
220 *
221 RCL 25
222 .7
223 *
224 +
225 RCL 26
226 SQRT
227 RCL 25
228 *
229 -.444
230 *
231 +
232 -26.0731
233 +
234 RCL 27
235 -.284
236 *
237 +
238 RCL 28
239 .404
240 *
241 +
242 RCL 29
243 -1.1
244 *
245 +
246 RCL 30
247 .646
248 *
249 +
250 19
251 +
252 CHS
253 E↑X
254 1
255 +
256 1/X
257 .85
258 *
259 1
260 X<>Y
261 -
262 LN
263 .2
264 LN
265 X<>Y
266 /
267 1/X
268 100
269 *
270♦LBL 40
271 RND
272 "STOCKING VALUE="
273 "⊢ "
274 ARCL X
275 AVIEW
276 ST+ 31
277 ADV
278 GTO 11
279♦LBL 12
280 -1
281 STO 27
282 STO 28
283 GTO 18
284♦LBL 13
285 0
286 STO 27
287 1
288 STO 28
289 GTO 18
290♦LBL 14
291 1
292 STO 27
293 0
294 STO 28
295 GTO 18
296♦LBL 15
297 -1
298 STO 29
299 STO 30
300 GTO 19
301♦LBL 16
302 0
303 STO 29
304 1
305 STO 30
306 GTO 19
307♦LBL 17
308 1
309 STO 29
310 0
311 STO 30
312 GTO 19
313♦LBL "SV"
314 ADV
315 "STOCKING VALUE "
316 "⊢MEAN= "
317 RCL 31
318 RCL 22
319 1
320 -
321 /
322 RND
323 STO 32
324 ARCL X
325 AVIEW
326 29
327 X<>Y
328 X>Y?
329 GTO 80
330 RCL 32
331 ADV
332 7.35
333 *
334 CHS
335 221
336 +
337 "ADV REPRO"
338 AVIEW
339 "NOT ADEQ."
340 AVIEW
341 "MIN SPROUTS NEE"
342 "⊢DED= "
343 ARCL X
344 AVIEW
345 STOP
346♦LBL 80
347 "ADV REPRO"
348 AVIEW
349 "ADEQUATE"
350 AVIEW
351 STOP
352♦LBL 95
353 PROMPT
354 FS? 00
355 GTO 96
356 FS? 01
357 GTO 60
358♦LBL 70
359 X<=Y?
360 X<>Y
361 FS? 00
362 XEQ 68
363 FS? 02
364 XEQ 65
365 ARCL X
366 AVIEW
367 STO IND 50
368 ISG 50
369 RTN
370 RTN
371♦LBL 60
372 CF 01
373 X=0?
374 GTO 40
375 GTO 70
376♦LBL 96
377 CF 00
378 X=0?
379 GTO 97
380 SF 00
381 GTO 70
382♦LBL 97
383 0
384 ST+ 31
385 ARCL X
386 AVIEW
387 FIX 0
388 GTO 40
389♦LBL 65
390 2.5
391 X<>Y
392 X>Y?
393 X<>Y
394 CF 02
395 RTN
396♦LBL 68
397 10
398 X<>Y
399 X>Y?
400 X<>Y
401 CF 00
402 RTN
403♦LBL 04
404 RCL IND 50
405 RCL 00
406 RCL 17
407 *
408 1/X
409 *
410 ARCL X
411 ISG 50
412 GTO 04
413 AVIEW
414 RTN
415♦LBL 05
416 STO 50
```

```
417 XEQ 04
418 CLA
419 RTN
420◆LBL 07
421 STO 20
422 1.1462
423 *
424 .4323
425 +
426 STO 21
427 RCL 21
428 RCL 18
429 *
430 .00211455
431 *
432 RCL 19
433 X↑2
434 .000511196
435 *
436 +
437 RCL 18
438 -.0564873
439 *
440 +
441 RCL 21
442 -.252517
443 *
444 +
445 2.23305
446 +
447 CHS
448 E↑X
449 1
450 +
451 1/X
452 RCL 21
453 1/X
454 18.3965
455 *
456 -.847819
457 +
458 CHS
459 E↑X
460 1
461 +
462 1/X
463 *
464 .8875
465 *
466 1
467 X<>Y
468 -
469 LN
470 .2
471 LN
472 X<>Y
473 /
474 1/X
475 RCL IND 50
476 *
477 RND
478 ST+ 48
479 STO IND 50
480 RTN
481◆LBL 06
482 STO 20
483 1.1462
484 *
485 .4323
486 +
487 STO 21
488 RCL 18
489 *
490 -.00101597
491 *
492 RCL 19
493 X↑2
494 .000415282
495 *
496 +
497 -.785279
498 +
499 CHS
500 E↑X
501 1
502 +
503 1/X
504 RCL 21
505 1/X
506 24.3594
507 *
508 -2.5782
509 +
510 CHS
511 E↑X
512 1
513 +
514 1/X
515 *
516 .8875
517 *
518 1
519 X<>Y
520 -
521 LN
522 .2
523 LN
524 X<>Y
525 /
526 1/X
527 RCL IND 50
528 *
529 RND
530 ST+ 48
531 STO IND 50
532 RTN
533◆LBL 08
534 STO 20
535 3.5
536 X<>Y
537 X>Y?
538 GTO 88
539 .46
540 RCL IND 50
541 *
542 RND
543 ST+ 48
544 STO IND 50
545 RTN
546◆LBL 88
547 RCL 20
548 1.1462
549 *
550 .4323
551 +
552 STO 21
553 .23840565
554 *
555 RCL 21
556 X↑2
557 .00278134
558 *
559 CHS
560 +
561 RCL 21
562 1/X
563 8.2488119
564 *
565 CHS
566 +
567 RCL 21
568 LOG
569 5.68040348
570 *
571 CHS
572 +
573 4.45376108
574 +
575 10↑X
576 RCL 21
577 X<>Y
578 -
579 STO 21
580 .59484
581 *
582 CHS
583 RCL 21
584 X↑2
585 100
586 /
587 +
588 1.02390
589 +
590 6.90428
591 +
592 CHS
593 E↑X
594 1
595 +
596 1/X
597 RCL 21
598 3
599 Y↑X
600 .00344484
601 *
602 RCL 21
603 X↑2
604 .161127
605 *
606 CHS
607 +
608 RCL 21
609 2.11955
610 *
611 +
612 6.11437
613 CHS
614 +
615 CHS
616 E↑X
617 1
618 +
619 1/X
620 *
621 .8875
622 *
623 1
624 X<>Y
```

```
625 -
626 LN
627 .2
628 LN
629 X<>Y
630 /
631 1/X
632 RCL IND 50
633 *
634 RND
635 ST+ 48
636 STO IND 50
637 RTN
638♦LBL 09
639 STO 20
640 RCL 18
641 60
642 X<>Y
643 X>Y?
644 GTO 99
645 .86
646 RCL IND 50
647 *
648 RND
649 ST+ 48
650 STO IND 50
651 RTN
652♦LBL 99
653 RCL 20
654 3.5
655 X<>Y
656 X>Y?
657 GTO 98
658 4
659 STO 20
660♦LBL 98
661 RCL 20
662 3
663 Y↑X
664 .0032
665 *
666 CHS
667 57.3
668 +
669 .00955
670 *
671 1
672 X<>Y
673 -
674 LN
675 .2
676 LN
677 X<>Y
678 /
679 1/X
680 RCL IND 50
681 *
682 RND
683 ST+ 48
684 STO IND 50
685 RTN
686♦LBL 55
687 .5
688 RCL IND 50
689 X<=Y?
690 0
691 ARCL X
692 ISG 50
693 GTO 55
694 AVIEW
695 RTN
696♦LBL 56
697 STO 50
698 XEQ 55
699 CLA
700 RTN
701 .END.
```

```
LABELS

                    CAT 1
LBL'OV
LBL'ST
LBL'AR
LBL'SV
.END.       1862 BYTES
```

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Sander, Ivan L.; Johnson, Paul S.; Rogers, Robert.
Evaluating oak advance reproduction in the Missouri Ozarks. Res. Pap. NC-251. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station; 1984. 16 p.

This guide presents a method for determining in advance of final harvest whether reproduction is adequate to reasonably ensure the regeneration of an oak stand in the Missouri Ozarks.

KEY WORDS: Quercus, stump sprouts, inventory, and final harvest.