MODAL DEVELOPMENT OF REGENERATION IN CLEARCUT RED OAK STANDS IN THE DRIFTLESS AREA

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The developmental potential of major tree species was quantified for clearcut northern red oak (Quercus rubra L.) stands in the Driftless Area of southwestern Wisconsin and adjacent Minnesota and Iowa. Using a non-linear regression model, stand age, site quality, and stocking of parent stand were used as predictors of the relative density of species-groups within defined height strata during the first 25 years after cutting. Average expected (modal) numbers of trees per acre in the upper stratum were calculated by species-groups from predicted relative densities and trends for numbers of trees for all species.

Predicted trends for numbers of trees in the upper stratum (intermediate through dominant crown classes) indicated that most new stands by age 25 generally will be dominated by black cherry (Prunus serotina Ehrh.), northern red oak stump sprouts, and hickories (Carya spp.), in that order. Relative density trends in the lower stratum did not indicate a strong development of any other species-group potentially capable of replacing species predominant in the upper stratum. Replacement of oak by sugar maple (Acer saccharum Marsh.) and American basswood (Tilia americana L.), the theoretical climax dominants, is occurring only in localized situations where these species were present before clearcutting. Thus, the average effect of clearcutting red oak forests is to create conditions favorable for non-commercial invaders and to reduce the relative importance of oaks.

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INTRODUCTION

Braun (1967) has described the "Driftless Area" of southwestern Wisconsin and adjacent Minnesota, Iowa and Illinois as lying within the maple-basswood forest region. Where seed sources of sugar maple (Acer saccharum Marsh.), American basswood (Tilia americana L.), and other tolerant species are present, these species can potentially replace less tolerant associates such as oaks (Quercus spp.) and hickories (Carya spp.) on favorable upland sites (Curtis 1959). On mesic sites, successional replacement may be very rapid where timber harvesting or other disturbances of oak-hickory overstories release tolerant understories. Conversely,

replacement may be slower in the absence of forest disturbance or on xeric sites where oak-hickory communities are relatively permanent.

Although forests of all stages of succession can be found in the Driftless Area, many stands are in early to intermediate stages and are dominated by mature northern red oak (Quercus rubra L.). These red oak communities occupy mesic to moderately xeric sites, and often contain few climax tolerants in the overstory or in the advance reproduction. Also typically absent or sparse is advance oak reproduction, a prerequisite for regenerating oaks (Sander 1971, Sander and Clark 1971). Thus, the probable course of stand development after harvest cutting has been unclear. This report describes developmental trends of important species during the first 25 years after clearcutting of stands which were predominantly northern red oak before cutting.

METHODS

Eighty 0.1-acre plots in 20 even-aged stands 5- to 23-years-old were located in southwestern Wisconsin and adjacent portions of Minnesota and Iowa. All stands were relatively free of recent disturbances from fire and grazing. On each plot, the present stand, stumps from the parent stand, and site factors were measured.

Parent Stands

A description of composition, basal area and stocking (Gingrich 1967) of parent stands was reconstructed from measurements of stump diameters converted to dbh (Horn and Keller 1957).

Present Stands

In stands less than 18 years old, heights and diameters of trees of seedling and seedling-sprout origin 5 feet tall or taller were measured on a 0.02-acre subplot within each 0.1-acre plot. Sprouts originating from stumps 3 inches or larger in diameter (stump sprouts) were measured on the entire 0.1-acre plot. In stands 18 years of age and older, all trees 5 feet tall or taller were measured within 0.1-acre plots. A multiple-stemmed clump of sprouts was counted as one tree and, except for red oak stump sprouts, only the largest stem per clump was measured and included in data analyses. In the red oak sprout clumps, total living basal area was measured in a subsample of 124 clumps. This facilitated adjustment of stand basal area for the relatively large numbers of sprouts within clumps of red oak stump sprouts.

Site

The topographic site coefficient (TSC) was used as a measure of site quality. TSC is a value that integrates depth of soil-plus-parent material, slope position, and aspect, which is correlated with red oak

stump sprout height growth (Johnson 1975). Values of TSC range from 0.10 (represented by upper southwest-facing slopes with thin soils) to 1.00 (represented by lower northeast-facing slopes with deep soils).

Analyses

A non-linear regression model (Hamilton 1974) was used to predict the relative density of a given species group expressed as a proportion of the total number of trees of all species within one of two defined height strata. In this context, relative density was used in a predictive and probabilistic sense, in contrast to its conventional usage as an observed percentage. The regression model restricted relative density estimates to a closed interval of 0 to 1. The observed value of the dependent variable (an individual tree) assumed a value of 1 when it was a member of a given species, or a value of 0 when it was not. Independent variables (predictors) were: (1) age of present stand (years), (2) site quality (TSC), (3) stocking of parent stand (percent) and (4) selected interactive combinations and transformations of 1, 2 and 3. To adjust for non-homogeneity of variance resulting from unequal sample plot sizes, individual trees were weighted by the reciprocal of the plot area in which they were sampled.

Because the customary measure of goodness-of-fit for regression relationships, the error mean square, is not appropriate when the dependent variable is dichotomous, goodness-of-fit was based on: (1) "t" tests that determine whether each of the estimated parameters is significantly different from 0, (2) an analysis of variance using the F statistic to test the significance of the variation explained by regression, and (3) a chi-square analysis that evaluates differences between observed and expected numbers of events within probability intervals for the range of predictions.

Regression fitting was done by trial and error deletion and reinclusion of selected variables in each species-group model. Final equations were selected from among 10 to 20 alternative models for each species-group on the basis of goodness-of-fit criteria and the biological logic of the models.

The analytical procedure assumes there are intrinsic and predictable time-dependent changes among the defined species-groups and strata, and that the stands sampled are representative of this successional process. Compositional changes are also assumed to be potentially dependent upon site quality and on parent stand stocking.

Because northern red oak stump sprouts are usually the important dominants in oak clearcuttings in the Driftless Area, they were selected as the basis for defining tree height strata. Two strata were defined: (1) the upper stratum, equal to or greater than 60 percent of the average height of red oak stump sprouts; and (2) the lower stratum, less than 60 percent of average stump sprout heights. The upper stratum generally

corresponded to intermediate, codominant and dominant crown classes; the lower stratum corresponded to the suppressed (overtopped) crown class.

Minimum heights defining the upper stratum were derived for each plot by regression from sprout height, age and site (TSC) relationships previously reported (Johnson 1975).[1/] Thus, there was a site- and age-dependent height value for each individual plot which determined whether an individual tree was within or outside of a given stratum. Of the 3,032 trees measured, 1,851 were in the upper stratum and 1,181 were in the lower stratum. In both strata, total numbers of trees were well-distributed over age and site classes represented.

In each of the two strata considered, regression relationships for each of the following 9 species-groups were tested:

(1) black cherry (*Prunus serotina* Ehrh.);
(2) elm: American (*Ulmus americana* L.) and slippery elm (*U. rubra* L.);
(3) hickory: shagbark (*Carya ovata* (Mill.) K. Koch) and bitternut hickory (*C. cordiformis* (Wang.) K. Koch);
(4) northern red oak of stump sprout origin;
(5) northern red oak of seedling and seedling-sprout origin;
(6) white oak (*Quercus alba* L.);
(7) subordinate species: eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch), and box elder (*Acer negundo* L.);
(8) aspen-birch: bigtooth (*Populus grandidentata* Michx.) and trembling aspen (*P. tremuloides* Michx.), and paper birch (*Betula papyrifera* Marsh.);
(9) miscellaneous mesophytes: sugar maple, red maple (*Acer rubrum* L.), American basswood, white ash (*Fraxinus americana* L.), black walnut (*Juglans nigra* L.) and butternut (*J. cinerea* L.).

In other analyses, linear regression was used to determine trends for trees-per-acre and basal area relationships based on plot summaries.

RESULTS

Parent Stands and Site

Northern red oak was the dominant species on most plots and white oak was the most important associated species (Table 1). Parent stands were essentially even-aged; dominant oaks averaged 84 years. Stocking based on Gingrich (1967) averaged 98 percent; the range was from 31 to

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[1/] Minimum values for the upper stratum (MVUS) in feet were determined by the following equation:

$$MVUS = -0.07 + 1.064\ (age) + 0.364\ (TSC)(age);$$
$$R^2 = 0.89,\ p < .01,\ n = 382,\ Sy.x = 2.65;$$

where: age = age of present stand;
TSC = topographic site coefficient.

149 percent. Basal areas averaged 121 square feet per acre and the tree of average basal area was 12.3 inches dbh. Parent stands were compositionally similar to those described by Curtis (1959) as "dry-mesic southern (Wisconsin) forests". Observed TSC values averaged 0.54 (approximately site index 60); they ranged from 0.19 to 0.98 (approximately site index 45 to 70).

Table 1. Average composition and structure of parent stands.

Species	Basal Area Per Acre (ft^2)	Trees Per Acre	Average DBH (inches)	Species-group Constancy[1/] (percent)
Northern red oak	99	81	15	100
White oak	13	29	9	76
Hickories[2/]	1	6	5	26
Black cherry	1	8	5	32
Elms[3/]	1	6	6	35
Other[4/]	6	17	8	45
Total	121	147	12	---

[1/]Constancy is the percent of plots containing a given species-group.
[2/]Shagbark and bitternut hickory.
[3/]American and slippery elm.
[4/]Includes: sugar maple, American basswood, black oak (*Quercus velutina* Lam.), bur oak (*Q. macrocarpa* Michx.), eastern hophornbeam, white ash, black walnut, butternut, red maple, trembling aspen, bigtooth aspen, and paper birch.

Relative Density

Upper Stratum: On all but the poorest sites, black cherry emerged as the most important species in the new stands, for which a predicted relative density of 0.14 at age 5 increased to 0.28 at age 25 (Fig 1 and Table 2). No significant relationship could be established between black cherry relative density and TSC or stocking of the parent stand.

The only species group to attain a predicted relative density higher than that for black cherry was hickory (0.39) at age 25 on poor sites where parent stand stocking was high (120 percent). However, hickory responded differentially to site quality, as measured by TSC; it increased in relative density with time on poor sites and decreased with time on good sites (Fig 2c). Based on chi-square analysis, there were significant

differences in the proportions of the two hickory species comprising the hickory group by site classes (averaged over all age classes): bitternut hickory accounted for 80 percent of all upper stratum hickories sampled on good sites, while shagbark accounted for 82 percent of hickories on poor sites; on medium sites, the two species were approximately equally represented. Thus, the relative density trends presented for the hickory group are weighted heavily by shagbark on poor sites, and by bitternut on good sites.

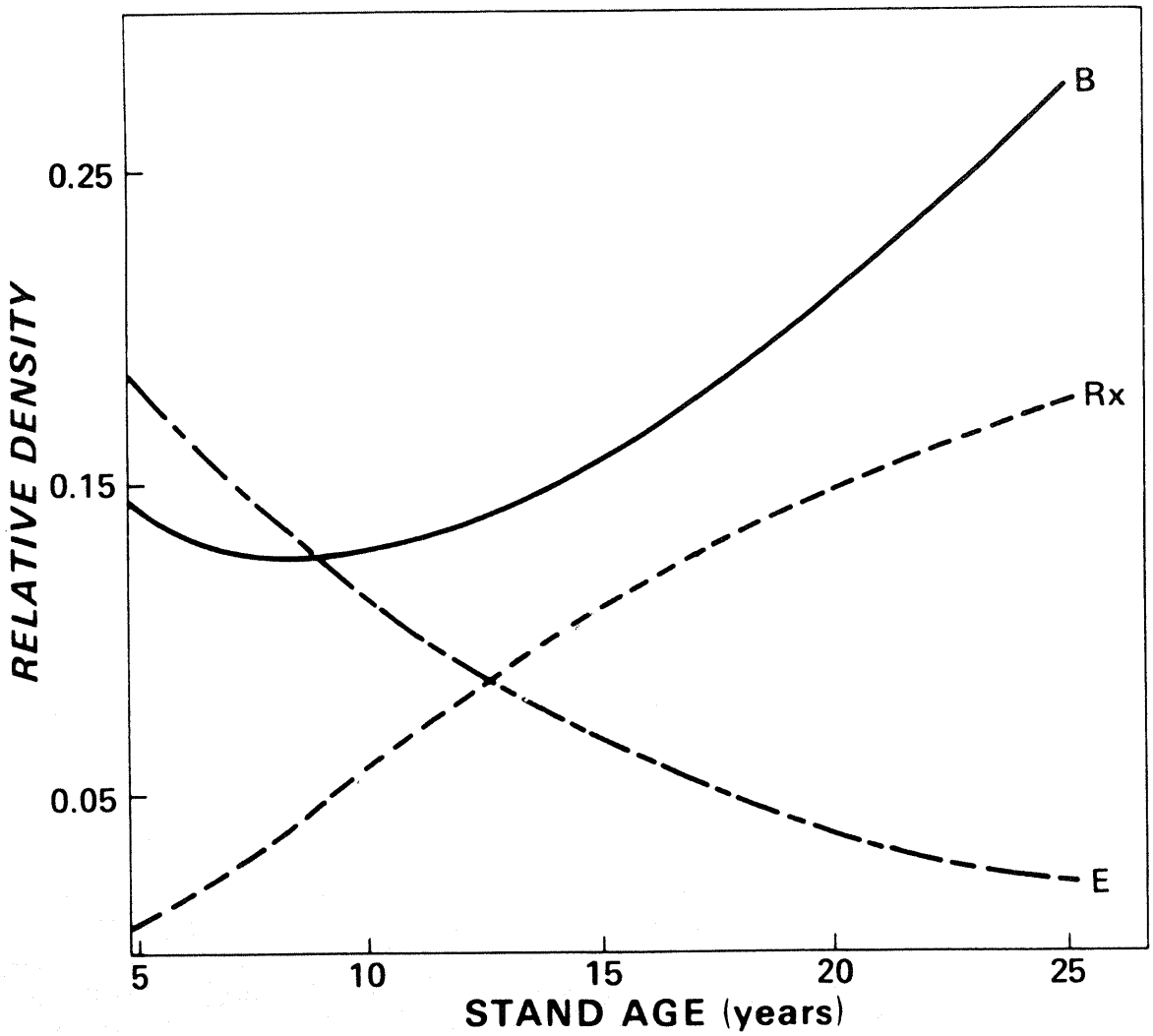


Figure 1. Relative density trends of upper stratum trees for 3 species-groups which showed no statistically significant relationship to topographic site coefficient or stocking of parent stand. (B = black cherry, E = elm, Rx = northern red oak stump sprouts; regression equations and goodness-of-fit statistics are given in table 2.)

Northern red oak stump sprouts also became more important with time; their predicted relative density values ranged from 0.01 at age 5 to 0.18 at age 25 (Fig 1). However, the analysis of stump sprouts was confounded by parent stand age, which tended to be younger in older clearcuts than in more recently created clearcuts (r = -0.60). Because of the higher frequency of stump sprouting in younger parent stands, there tended to be more clumps of red oak stump sprouts per acre in older clearcuts than in young clearcuts. Thus, relative density estimates for red oak stump sprouts were somewhat lower in young clearcuts and higher in old clearcuts than they would have been if parent stand age had deviated little from its mean. No statistically significant relationship could be established between relative density of red oak stump sprouts and TSC or parent stand stocking.

Red oaks of seedling and seedling-sprout origin were poorly represented at all ages; their maximum relative densities were only 0.07. However, at age 25, trends for predicted relative density decreased from 0.07 to 0.01 as stocking of the parent stand increased from 60 to 120 percent (Fig 2a).

Predicted relative densities of white oak increased with time on all sites, but reached a maximum value of 0.19 on the best sites (TSC = 1.0) at age 25 (Fig 2b).

The sum of the relative densities for red and white oak groups increased with stand age; at age 25, values ranged from 0.14 to 0.40, depending on site and parent stand stocking. The relative density for combined oak groups increased as TSC increased, but decreased as parent stand density increased. Thus, at age 25 on poor sites where parent stand density was high, combined oaks are predicted to account for 24 percent of upper stratum trees; at this same age on good sites where parent stand density was low, oaks are predicted to account for 40 percent of upper stratum trees. On the average, clumps of northern red oak stump sprouts will account for 1/2 to 2/3 of all upper stratum oaks by age 25.

The subordinate species group (Fig 2d) and the elm group (Fig 1) both decreased in importance with time. However, the subordinate species group was better represented on poor sites at age 5 (relative density = 0.18) than on other sites or at other ages. Eastern hophornbeam was the predominant member species of this group. Despite its general classification as a tolerant mesophyte, it was better represented on poor sites than on good sites.

The elms attained a relative density of 0.18 at age 5 but declined to a predicted value of 0.02 by age 25 (Fig 1). Elm was not significantly related to TSC or to parent stand stocking. This species group contained two species, American and slippery elm, which were about equally represented on average sites. However, American elm was predominant on poor sites (88 percent) and good sites (100 percent). A similar site distribution pattern was apparent when elms of all sizes were combined.

Table 2. Regression coefficients and goodness-of-fit statistics for predicting relative density.[1/]

Species-group & Stratum	B_0	Independent X_1	X_2	X_3
				regression
NORTHERN RED OAK				
Non-stump sprouts:				
Upper stratum	-5.0286**[4/]	.1734*		.0698**
Lower stratum	8.4835**	-.4090**		
Stump sprouts:				
Upper stratum	0.7424**			
WHITE OAK				
Upper stratum	-5.4835**	.0847**	1.9483**	
Lower stratum	6.1140**	-.2379**		
HICKORY				
Upper stratum	-1.5588^{ns}		2.8320**	-.0392**
Lower stratum	-5.5162**	.1670**		
BLACK CHERRY				
Upper stratum	-3.0673**	.0849**		
Lower stratum	-2.6309**	.0763*		
ELM				
Upper stratum	-0.9252**	-.1123**		
Lower stratum	-0.7586**	-.1345**		
SUBORDINATE SPECIES				
Upper stratum	-1.4381**	-.0401*	-0.9597*	
Lower stratum	-3.5054**			.0480*

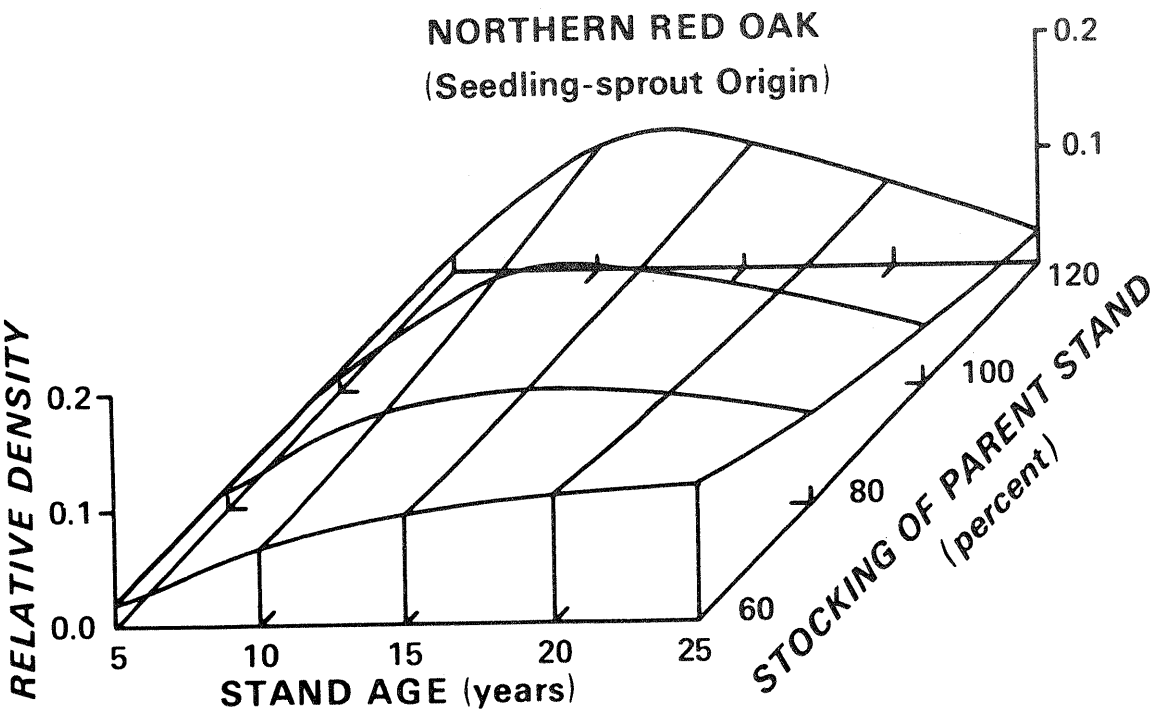
[1/] Equations are of the form: $\hat{Y} = \{1 + \exp[-(B_0 + B_1X_1 + \ldots B_nX_n)]\}^{-1}$.

[2/] X_1 = Stand age (years) = AGE
X_2 = Topographic site coefficient = TSC
X_3 = Stocking of parent stand (percent) = STOCK
X_4 = 1/AGE
X_5 = STOCK/AGE
X_6 = STOCK x AGE
X_7 = TSC x AGE
X_8 = STOCK^2
X_9 = STOCK x AGE^2

Variables[2/]						
X_4	X_5	X_6	X_7	X_8	X_9	Chi-squared[3/]
coefficients						
	-.2722**	-.0036**				ns
-54.8613**						ns
-20.3264**						ns
						ns
-64.0276**						ns
	.1112**	.0021**	-.2680**			*
17.2432**						*
5.5240ns						ns
3.8499ns						ns
						**
						**
						ns
				-.0004**	.00003**	ns

[3/] Chi-square analyses were used to evaluate differences between observed and expected numbers of occurrences of trees within a given stratum among relative density intervals of width .05; significance levels are: * = .05, ** = .01, ns = non-significant.

[4/] Significance levels are based on "t" tests (H_o: B = 0) and are defined as above; p <.01 for all regression F tests.



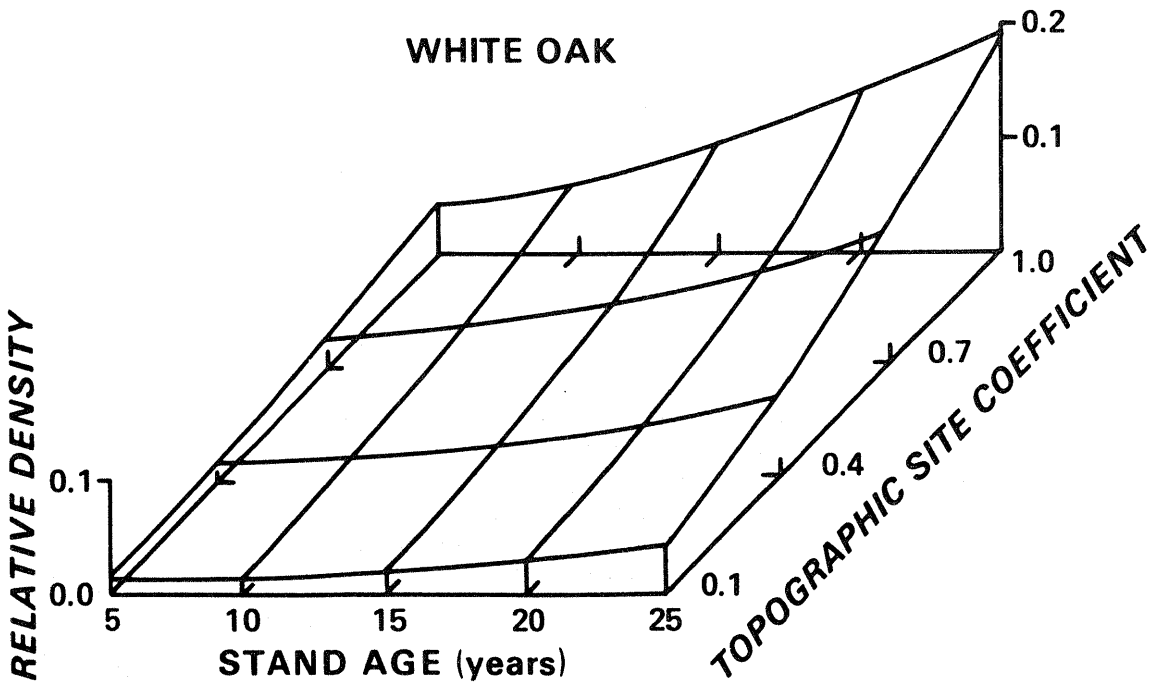
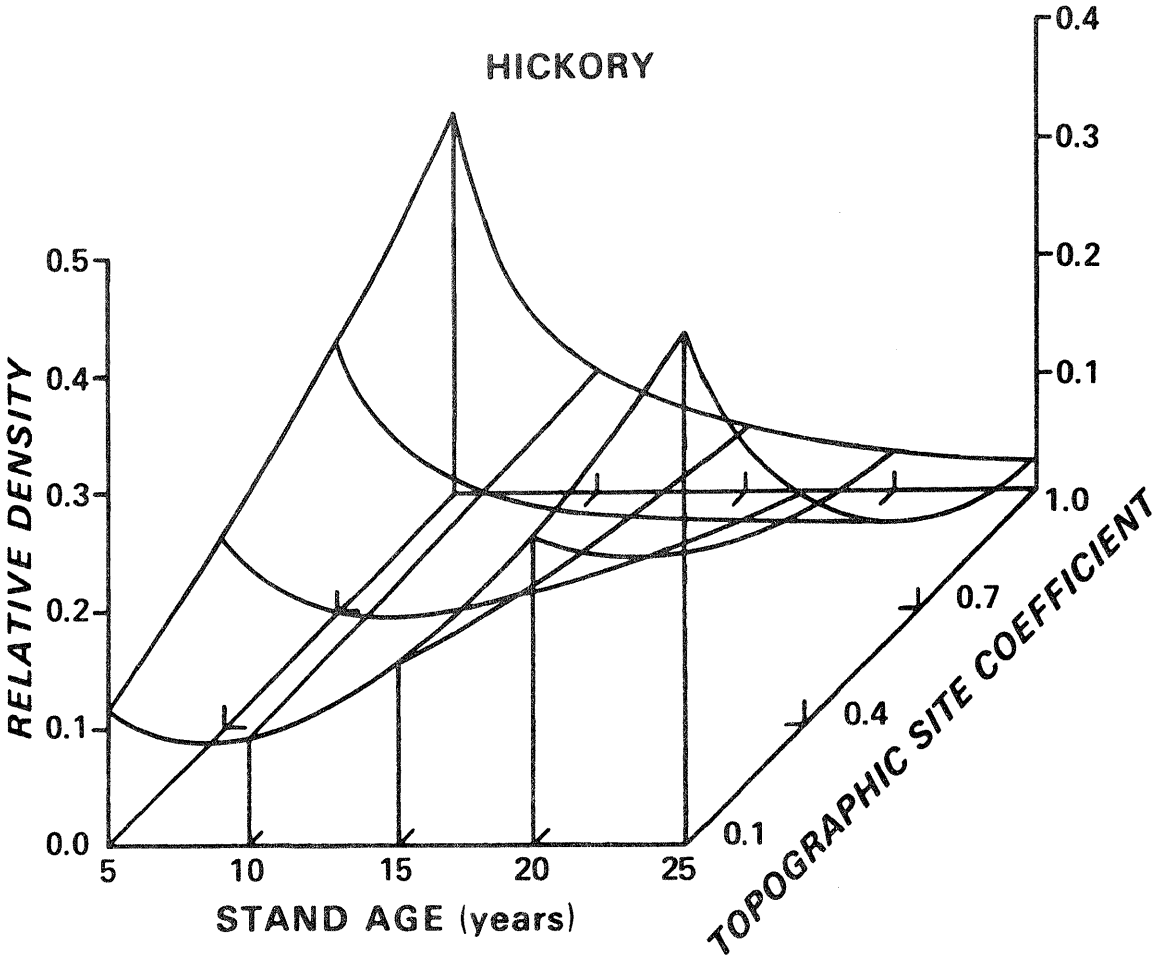


Figure 2. Relative density trends of upper stratum trees for northern red oak (a) and white oak (b) in relation to topographic site coefficient or stocking of parent stand. Regression equations and goodness-of-fit statistics are given in table 2.



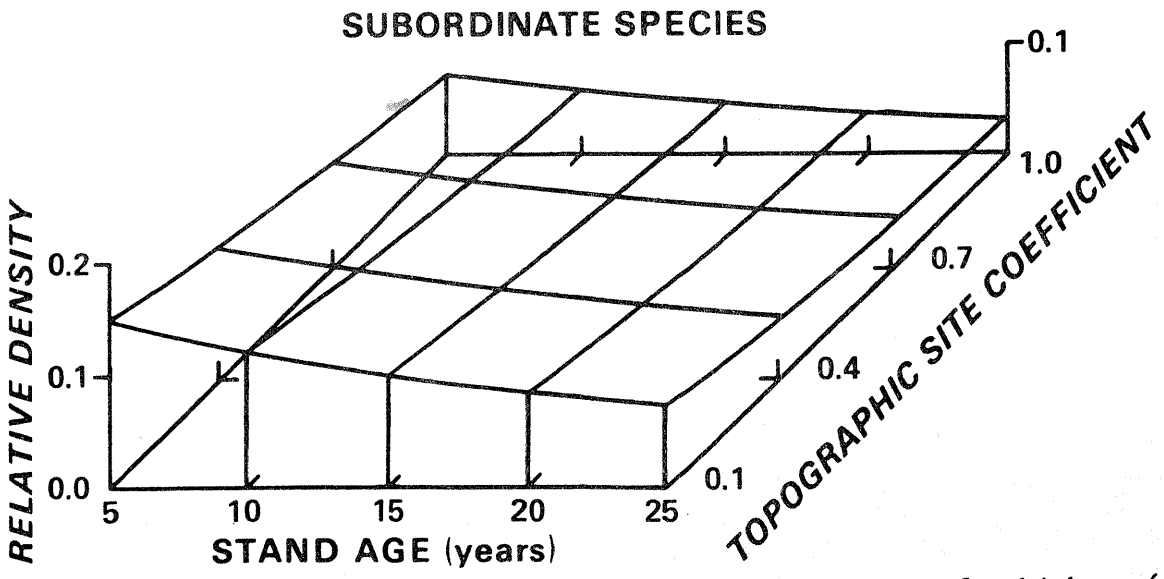


Figure 2. (Cont.) Relative density trends of upper stratum trees for hickory (c) and subordinate species (d) in relation to topographic site coefficient or stocking of parent stand. Parent stand stocking is held at 100 percent for hickory. Regression equations and goodness-of-fit statistics are given in table 2.

The aspen-birch and miscellaneous mesophyte groups showed no statistically significant relationships to stand age, TSC, or parent stand stocking. Based on the sum of all relative density values for which there were statistically significant trends, the relative density of these "other" species at age 25 reached a maximum value of 0.27 on good sites where parent stand stocking was moderately high to high. At age 25, "other" species were most poorly represented on good sites, where parent stand stocking was over 100 percent.

Lower Stratum: Among lower stratum trees, 6 of the 9 species groups considered exhibited significant relative density trends in relation to stand age. Except for the subordinate species group, no significant relationship with TSC or parent stand stocking could be established. In the subordinate group, relative density decreased as parent stand stocking increased.

Among all species groups in the lower stratum, black cherry attained the highest predicted relative density, increasing in importance from 0.18 at age 5 to 0.36 at age 25 (Fig 3). Hickory also increased in importance with stand age; it attained a predicted value of 0.22 at age 25; the subordinate group exhibited a similar trend. Lower-stratum elm paralleled its behavior in the upper stratum, decreasing from a relative density high of 0.19 at age 5 to 0.02 at age 25. Both white oak and northern red oaks of seedling and seedling-sprout origin exhibited relative density peaks near the middle of the age range.

Trees Per Acre

Numbers of trees per acre represented by the 80 sample plots were extremely variable (Fig 4). However, there was a statistically significant, although weak, relationship between total number of trees per acre versus stand age plus parent stand stocking ($R^2 = 0.19$). The relationship was similar and slightly improved statistically ($R^2 = 0.25$) when only upper stratum trees were considered. Despite the large amount of unexplained variation, the latter trends provided a basis for estimating expected average or "modal" numbers of trees per acre for the upper stratum by species groups using the predicted relative densities thusly:

> (relative density of species group) x (total number of trees of all species per acre) = modal number of trees per acre in species group.

To quantify compositional trends expressed as trees per acre, modal numbers of trees per acre were calculated for upper stratum trees on average sites (TSC = 0.55) and for four levels of parent stand stocking (Table 3). Total number of trees per acre were highest where parent stand stocking was highest. At age 5, predicted numbers of trees per acre were over twice as great at 120 percent parent stand stocking (1,208 per acre) as at 60 percent parent stand stocking (503 per acre). However, these differences declined to 297 and 250 trees per acre, respectively, by age 25.

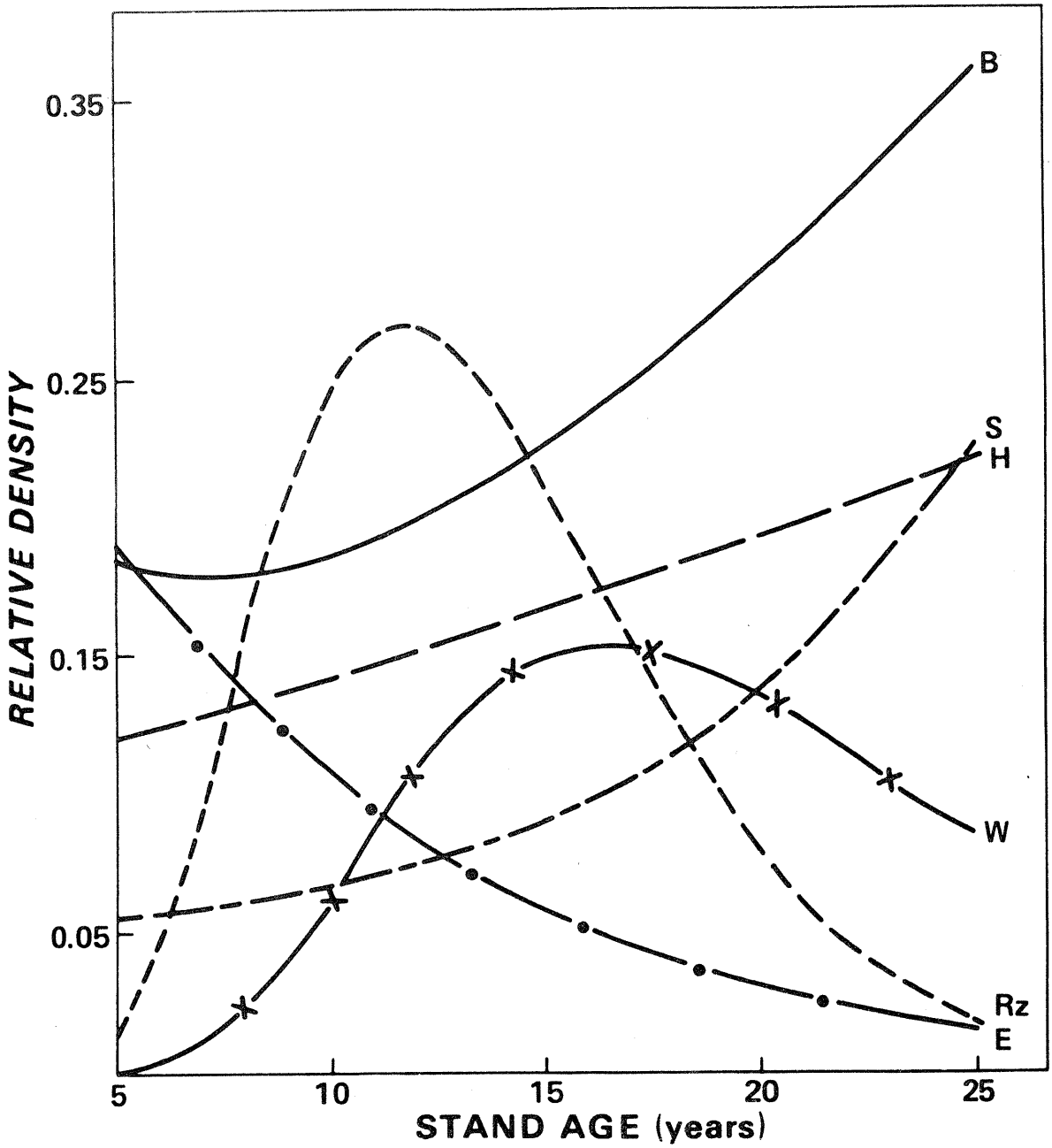


Figure 3. Relative density trends of lower stratum trees for 6 species-groups. (Rz = northern red oak of seedling and seedling-sprout origin, W = white oak, H = hickory, E = elm, B = black cherry, S = subordinate species (stocking of parent stand held constant at 100 percent); regression equations and goodness-of-fit statistics are given in table 2.)

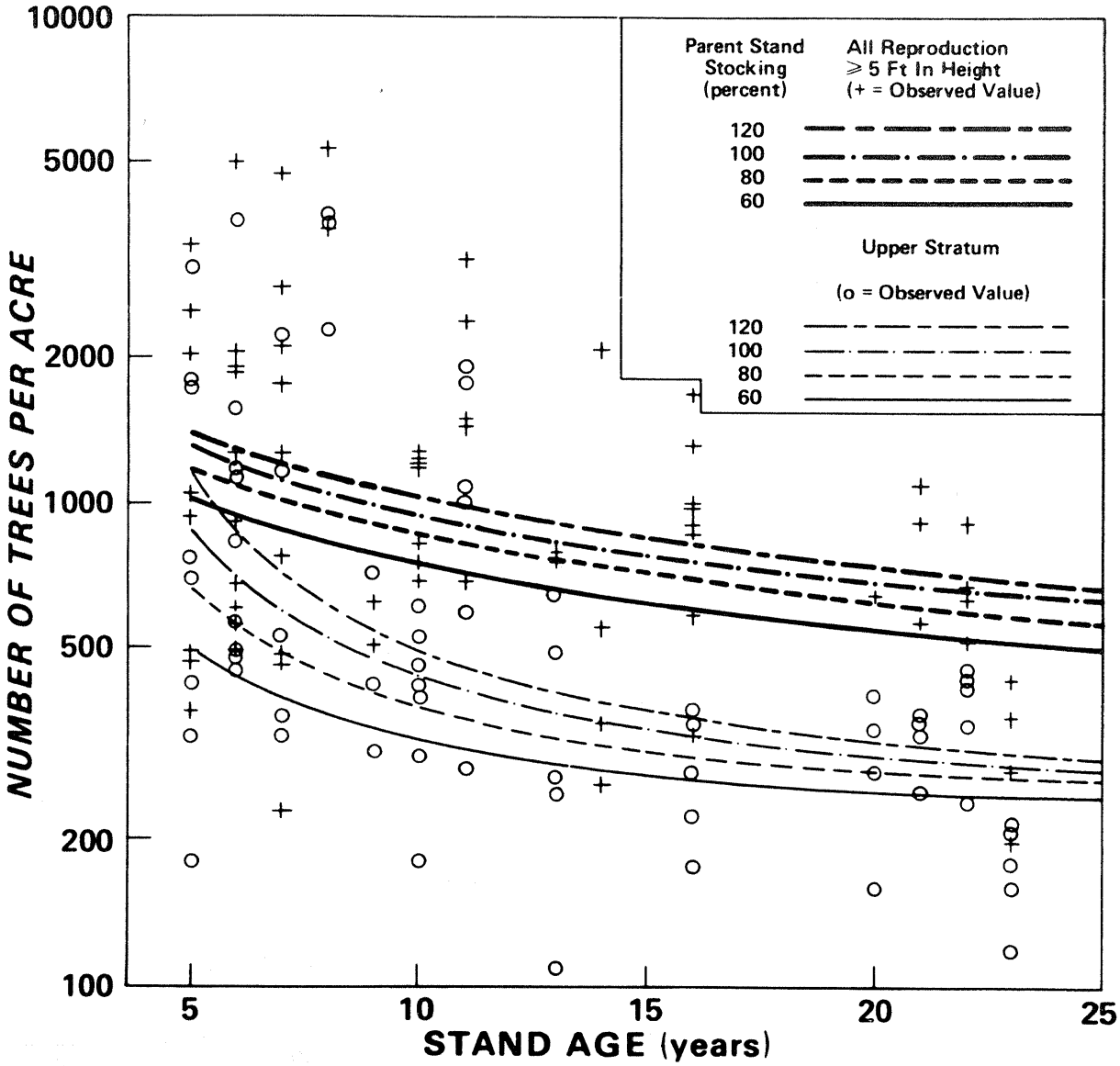


Figure 4. Observed values and trends for number of trees per acre in relation to stand age and stocking of parent stand. ($\log_{10}$(number of trees per acre $\geq$ 5 ft in height) = 2.5202 + 0.4504($\log_{10}$ [(number of trees per acre in upper stratum)/(stand age in years)]); R^2 = 0.19, Sy.x = 0.29, n = 80, $p < .01$; ($\log_{10}$(number of trees per acre in upper stratum) = 2.3212 + 0.0317 [(parent stand stocking percent)/(stand age in years)]; R^2 = 0.25, Sy.x = 0.36, n = 80, $p < .01$.)

Table 3. Modal number of trees per acre in the upper stratum on average sites (TSC = 0.55).

Stand Age (years)	Stocking of parent stand (percent)	Species-Group								
					Northern Red Oak					
		Elm	Black Cherry	Hickory	Stump Sprouts	Nonstump Sprouts	White Oak	Sub-ordinate Species	Other Species	Total
5	60	93	73	123	4	6	9	52	143	503
10		37	42	42	19	17	9	28	131	325
15		19	45	27	31	19	12	20	107	280
20		11	55	20	39	19	16	15	86	261
25		6	69	17	44	17	23	12	62	250
5	80	124	98	149	6	8	12	69	208	674
10		43	49	42	23	22	10	32	155	376
15		21	49	29	34	21	13	22	120	309
20		11	58	25	42	15	17	17	95	280
25		6	73	24	47	10	24	13	68	265
5	100	166	130	179	8	11	16	93	299	902
10		50	56	43	26	28	12	37	182	435
15		23	54	32	38	22	14	24	134	341
20		12	63	31	45	12	19	18	102	302
25		6	77	34	49	6	26	14	68	280
5	120	223	175	216	10	13	22	124	425	1208
10		57	65	44	30	37	14	43	213	503
15		26	60	35	42	22	15	27	149	376
20		13	68	39	48	10	20	19	108	325
25		7	82	49	52	3	27	15	62	297

On average sites, the three oak groups when combined accounted for 81 to 84 trees per acre by age 25; over half of these were comprised of clumps of northern red oak stump sprouts (each clump counted as 1 "tree"). Fewer than 20 northern red oak per acre of seedling or seedling-sprout origin were predicted to be present in the upper stratum at age 25, regardless of parent stand stocking. The increase in predicted numbers of red oak stump sprouts per acre is largely related to the confounding of parent stand age and present stand age. Theoretically, numbers of stump sprouts in the upper stratum should remain relatively constant or even slightly decrease with age of the present stand because of expected mortality. Thus, modal numbers of red oak stump sprouts given are lower in younger clearcuts and slightly higher in older clearcuts than we would expect had parent stand age not been correlated with present stand age.

Black cherry was the most abundant species in the upper stratum at age 25: predicted numbers ranged from 69 at 60 percent parent stand stocking to 82 at 120 percent stocking. However, there tended to be more elms and hickories than black cherry at younger stand ages in the upper stratum, which emphasized the rapid dropout rate of the elms and hickories.

Basal Area Per Acre

Although non-oaks outnumbered oaks by a ratio of about 2:1 at 25 years in the upper stratum (red oak sprout clumps counted as 1 "tree"), basal area differences between the two groups were narrower (Fig 5). Non-oaks contributed slightly more to total basal area per acre than oaks during the first 20 years of stand development. However, trends for the two groups intersected at about age 21 when both averaged between 28 and 29 square feet per acre of basal area. The surge in oak basal area growth after age 20 was largely attributable to clumps of multiple-stemmed northern red oak stump sprouts. By age 25, total basal area was estimated at 88 square feet per acre; oak accounted for 56 percent.

DISCUSSION

Marks (1942) related the ecological conditions that created the Driftless Area red oak forests to recurrent fires set by Indians during a 100-year period that ended with the arrival of European settlers in the mid-eighteen hundreds. These fires apparently also eliminated much of the fire sensitive maple-basswood forest. When such burning stopped, however, areas described as "scrub" by the early surveyors quickly developed into the dense stands of oak present today. In present stands, neither sugar maple nor American basswood, the theoretical climax dominants, occur as consistently important components. On the sample plots, both species were characterized by low constancy in both parent stands and new stands. However, where sugar maple had been well represented in the parent stand, it was also well represented in the new stand; this emphasizes its potential to succeed oak where seed sources are present.

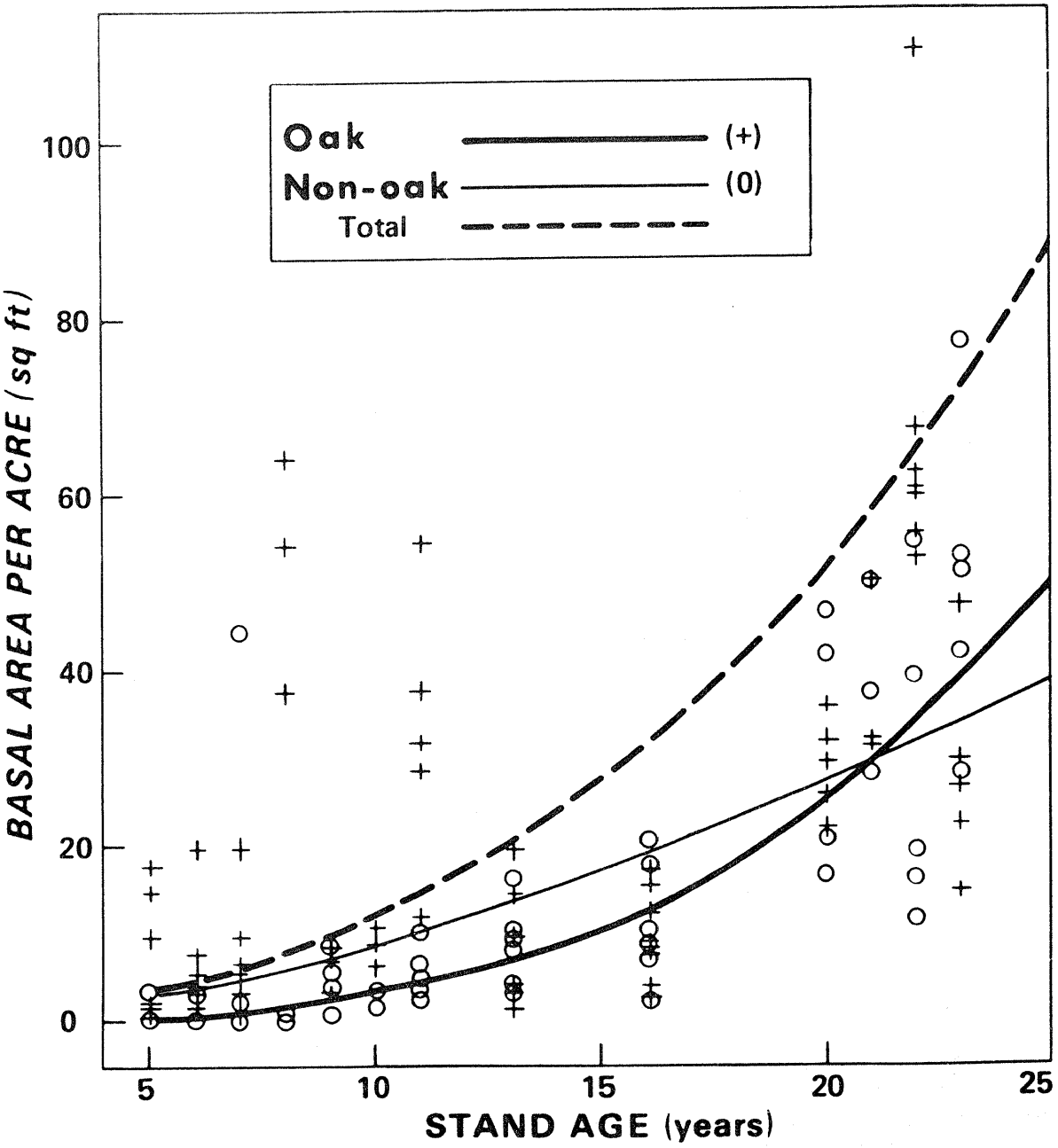


Figure 5. Observed values and trends of basal area per acre. ($\log_{10}$(oak basal area per acre in sq ft) = -2.6690 + 3.1202 ($\log_{10}$(stand age in years))); R^2 = 0.77, Sy.x = 0.39, n = 80, p < .01; $\log_{10}$(non-oak basal area per acre in sq ft) = -0.6502 + 1.5986($\log_{10}$(stand age in years)); R^2 = 0.39, Sy.x = 0.45, n = 80, p < .01; total oak basal area = oak + non-oak.)

One of the most ecologically significant features of mature oak forests in the Driftless Area is their dense shrub layer. Auclair and Cottam (1971) found that shrub canopies in southern Wisconsin oak forests can reduce light intensity at ground level to 1 or 2 percent of full light. They pointed out that such shrub canopies intercept both light and precipitation, and strongly compete with tree seedlings. Moreover, shrub densities were found to be inversely related to overstory density. Thus, in the present study, the positive correlation between stocking of the parent stand and total number of trees per acre in the new stand (Fig 4) may be caused by the regeneration-depressing effects of high shrub densities at low overstory stand densities.

They attributed the importance of black cherry in southern Wisconsin oak forests to its "opportunistic" characteristics including widespread dispersal, delayed germination of seeds, and flexible seedbed requirements. Similarly, elms, hickories, box elder, and aspen also invade disturbed oak forests; however, individually they didn't usually attain the importance of black cherry. A preponderance of such opportunistic invaders gives rise to patterns of species replacement that Auclair and Cottam have described as irregular and the result of chance dispersal and local catastrophes rather than orderly and predictable succession.

The failure of oak to reassert itself as advance reproduction is emphasized in the low relative densities and modal numbers of trees per acre for northern red oak of seedling and seedling-sprout origin and white oak. This failure is apparently not related to the lack of seedling establishment *per se*, but rather to inadequate growth of seedlings after initial establishment. This is supported by Scholz's (1959) findings that red oak seedlings numbered over 2,500 per acre but averaged less than 8 inches in height 7 years after a good acorn crop and excellent initial seedling establishment in a Driftless Area red oak forest. Similarly, in another Driftless Area red oak stand, northern red and white oak advance reproduction averaged 1,431 stems per acre, but 80 percent of these were less than one foot in height; only 31 per acre were 5 feet in height or larger (Arend and Scholz 1969).

In upland hardwood stands in Iowa, developmental failures of northern red oak reproduction were ascribed to both light and soil moisture deficiencies based on seedling growth and photosynthesis studies and a review of environmental conditions under forest canopies (Musselman and Gatherum 1969). In such environments, root development of northern red oak is depressed (dry weight basis) relatively more than shoot development (Musselman and Gatherum 1969, Scholz 1955). Failure of oak roots to develop is especially significant because of the positive correlation between root mass and shoot growth. This correlation has been demonstrated directly by root weight-shoot growth relationships in planted oak seedlings (Larson 1975) and indirectly by root collar diameter-shoot growth correlations in natural oak reproduction (Sander 1971) and the rapid growth of oak shoots originating from large stumps (Johnson 1975, Wendel 1975). Under conditions typical of Driftless Area red oak stands,

few root systems of oak advance reproduction develop that can sustain rapid shoot growth following overstory release. This is evidenced by the small number of oaks of seedling or seedling-sprout origin that reach the upper stratum.

Recently developed criteria for regenerating oak forests under even-aged management require that there be at least 433 well-developed oak advance reproduction stems per acre no less than 4.5 feet in height at the time of clearcutting to ensure adequate regeneration of oaks of seedling or seedling-sprout origin after final harvest cutting (Sander et al. 1976).[2/] These criteria are based on a minimum goal of 221 codominant or larger oaks when the new stand is about 20 years old. In contrast, the developmental trends for clearcut Driftless Area red oak stands suggest that, on the average, there will be only 70 to 100 upper stratum oaks per acre (including stump sprouts) at age 25, or about 1/3 of that required to meet minimum stocking needs assuming no other "acceptable" species are present.

SUMMARY AND CONCLUSIONS

The net effect of clearcutting in Driftless Area red oak forests is to create conditions that favor non-commercial invaders such as black cherry, elms, hickories, box elder, eastern hophornbeam and aspens. During the first 25 years, black cherry emerged as the most important species in both the upper and lower stratum on all but the poorest sites. On poor sites, shagbark hickory became the most important species in the upper stratum by age 25. Bitternut hickory was abundant on good sites at early ages, but rapidly declined in importance with time. Elms in both strata similarly declined with time.

Oaks in the upper stratum increased with time but rate of increase was greatest on good sites and where parent stand stocking was high. However, clumps of northern red oak stump sprouts accounted for one-half or more of all upper stratum oaks on all sites by age 25. Largely because of fast-growing, persistent stems within red oak sprout clumps, total living basal area of oaks was nearly equal to that of non-oaks by age 20.

The trends suggest that longer-term patterns of overstory development will involve relatively unpredictable changes among largely non-commercial, non-oak species of similar tolerance and replacement potential. In successive generations, the oak component will probably continue to decline in importance because of its apparent inability to reproduce under prevailing conditions, and because of the gradual reduction of the number of oaks from which stump sprouting can occur.

[2/] However, predicted numbers of oak stumps with sprouts can be used to compensate for deficiencies in oak advance reproduction.

Future compositional shifts toward maple-basswood are unlikely because of the prevailing absence of seed sources of these species. Nevertheless, where site conditions are suitable and seed sources are available, succession toward more mesophytic forests proceeds rapidly. This process can potentially be accelerated by artificial regeneration of mesophytic species, such as sugar maple, red maple, and white ash, which have been successfully planted in oak clearcuts in southern Wisconsin (Johnson 1976). In contrast, the artificial regeneration of oaks has generally not been successful in the Driftless Area or elsewhere (Johnson 1976, Russell 1971).

LITERATURE CITED

Arend, John L. and Harold F. Scholz. 1969. Oak forests of the lake states and their management. USDA Forest Serv. Res. Pap. NC-31, 36 pp. North Cent. Forest Exp. Stn., St. Paul, Minn.

Auclair, Allan N. and Grant Cottam. 1971. Dynamics of black cherry (Prunus serotina Ehrh.) in southern Wisconsin oak forests. Ecol. Monogr. 41(2):153-177.

Braun, E. Lucy. 1967. Deciduous forests of eastern North America. New York: Hafner. 596 pp.

Curtis, John T. 1959. The vegetation of Wisconsin. Madison: The University of Wisconsin Press. 657 pp.

Gingrich, S. F. 1967. Measuring and evaluating stocking and stand density in upland hardwood forests of the central states. Forest Sci. 13(1):38-53.

Hamilton, David A., Jr. 1974. Event probabilities estimated by regression. USDA Forest Serv. Res. Pap. INT-152, 18 pp. Intermt. Forest and Range Exp. Stn., Ogden, Utah.

Horn, A. G. and R. C. Keller. 1957. Tree diameter at breast height in relation to stump diameter by species group. USDA Forest Serv. Tech. Note 507, 2 pp. Lake States Forest Exp. Stn., St. Paul, Minn.

Johnson, Paul S. 1975. Growth and structural development of red oak sprout clumps. Forest Sci. 21(4):413-418.

Johnson, Paul S. 1976. Eight-year performance of interplanted hardwoods in southern Wisconsin oak clearcuts. USDA Forest Serv. Res. Pap. NC-126, 9 pp. North Cent. Forest Exp. Stn., St. Paul, Minn.

Larson, M. M. 1975. Pruning northern red oak nursery seedlings: effects on root regeneration and early growth. Canadian J. Forest Res. 5(3): 381-386.

Marks, John B. 1942. Land use and plant succession in Coon Valley, Wisconsin. Ecol. Monogr. 12(2):114-133.

Musselman, R. C. and G. E. Gatherum. 1969. Effects of light and moisture on red oak seedlings. Iowa State J. of Sci. 43(3):273-284.

Russell, T. E. 1971. Seeding and planting upland oaks. In Oak Symposium Proceedings, pp. 49-54. USDA Forest Serv., Northeast. Forest Exp. Stn., Upper Darby, Pa.

Sander, Ivan L. 1971. Height growth of new oak sprouts depends on size of advance reproduction. J. Forestry 69(11):809-811.

Sander, Ivan and F. Bryan Clark. 1971. Reproduction of upland hardwood forests in the central states. USDA Agric. Handb. 405, 25 pp. USDA Forest Serv., Washington, D.C.

Sander, Ivan L., Paul S. Johnson and Richard F. Watt. 1976. A guide for evaluating the adequacy of oak advance reproduction. USDA Forest Serv. Gen. Tech. Rep. NC-23, 7 pp. North Cent. Forest Exp. Stn., St. Paul, Minn.

Scholz, Harold F. 1955. Growth of northern red oak seedlings under variable conditions of ground cover competition. USDA Forest Serv. Tech. Note 430, 2 pp. Lake States Forest Exp. Stn., St. Paul, Minn.

Scholz, Harold F. 1959. Further observations on seedbed scarification show benefits to northern red oak were temporary. USDA Forest Serv. Tech. Note 555, 2 pp. Lake States Forest Exp. Stn., St. Paul, Minn.

Wendel, G. W. 1975. Stump sprout growth and quality in several Appalachian hardwood species after clearcutting. USDA Forest Serv. Res. Pap. NE-329, 9 pp. Northeast. Forest Exp. Stn., Upper Darby, Pa.

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