RELATIONSHIPS BETWEEN BIOTIC AND ABIOTIC FACTORS AND REGENERATION OF CHESTNUT OAK, WHITE OAK, AND NORTHERN RED OAK

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ABSTRACT.—A series of substantial field surveys of 38 mixed-oak stands in central Pennsylvania were carried out during 1996–2000. All the stands were surveyed 1 year prior to harvest, and 16 stands have been surveyed 1 year after harvest. Three abiotic factors at stand scale, four abiotic factors at plot scale, and two biotic factors and one abiotic factor at subplot scale was used to analyze their relationships to the abundance and composition of regeneration. Stand scale factors were the most influential factors on oak regeneration. Stand aspect together with slope position explained most of the variation in abundance of both advanced and post-harvest regeneration. Plot slope shape and exposure angle played an important position in oak regeneration. All biotic factors at subplot scale had a strong correlation with regeneration abundance. In general, light factors (stand aspect and exposure angle), other physical conditions (slope position and slope shape), and canopy composition immediately above the plot played strong roles in regeneration in these mixed-oak stands.

Throughout eastern Northern America, natural regeneration of oaks is often difficult to obtain even where oaks are dominant components in the overstory before harvest. Although the problem is widespread both geographically and by species, there is no apparent universal solution. The major causes of regeneration difficulty may change from site to site and region to region. Because of this variability, we need to view "the oak regeneration problem" as having both local and regional aspects (Lorimer 1992). As Crow (1988) has pointed out for northern red oak, specific prescriptions for local conditions are needed to supplement general guidelines for regenerating oak.

In this paper, we describe some results pertaining to the relationship between oak regeneration and stand conditions from field surveys of 38 mixed-oak stands in Pennsylvania carried out during 1996 to 2000. All the stands were surveyed 1 year prior to harvest, and 16 stands have also been surveyed 1 year after harvest. In each stand, depending on the stand size, 15 to 30 permanent plots with a radius of 26.3 feet (20^{th}-arce plots) were spaced systematically in a square grid to represent the whole stand. Four permanent subplots with a radius 3.72' (milacre plots), were set up within each plot at 16.5 feet from the 20^{th}-acre plot center along each cardinal direction. All together, we measured 4,012 subplots before harvest and 1,600 subplots 1 year after harvest.

Regeneration density and size were sampled in each subplot by species. Biotic and abiotic factors were also recorded at the stand, plot, and subplot level. The following biotic and abiotic factors were measured in the field survey:

- Stand scale: elevation, slope position, and slope aspect;
- Plot scale: slope shape (sum of percentage slope uphill, down hill, and at 90º to aspect; + values = concavity; - values = convexity), slope percentage, exposure angle (the angle between the visible east horizon and west horizon), and slope aspect;
- Subplot scale: micro-topography (mound, slope, pit, and flat), closest canopy species, distance to closest canopy tree, largest canopy species over plot, and distance to largest canopy tree.

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Oak regeneration quantity and quality (size) were both very important to ensure successful oak regeneration, but in this paper we mainly focused on regeneration. Analysis of variance was performed in SAS by using a linear nested model to examine relationships between the above variables and regeneration density of chestnut oak (*Quercus prinus* L.), northern red oak (*Q. rubra* L.), and white oak (*Q. alba* L.).

Before harvest, stand basal area for all the stands surveyed ranged between 72 and 130 ft^2/ac, with oak species representing 31 to 91 percent of the total (typically >50 percent). After modified either by a clearcut or shelterwood harvest, the basal area of the remaining trees ranged from 7 to 52 ft^2/ac, and most of the remaining overstory trees were oaks. Over all of the surveyed stands, the major oak regeneration species for both pre-harvest and post-harvest assessment were chestnut oak (3,004 and 4,467 stems/acre before and after harvest, respectively), northern red oak (2,149 and 1,237 stems/acre, respectively) and white oak (799 and 489 stems/acre, respectively).

Red maple (*Acer rubrum* L.) was the most abundant regeneration species (21,462 and 14,613 stems/acre before and after harvest). Sweet birch (*Betula lenta* L.), although not widely distributed all over the region, had occurrences of regeneration density as high as 8,300 stems/acre in several stands after harvest. Since not all the stands have yet been surveyed 1 year after harvest, the sample sizes are different before and after harvest. Hence it is not quite appropriate to compare regeneration abundance before and after harvest because of possible sample bias. Nevertheless, as a trend, average regeneration density decreased after harvest for red maple, northern red oak, and white oak, but increased for chestnut oak.

The results of linear nested models showed that stand level attributes were the most influential factors affecting oak regeneration abundance. In all the nested models, site always had a significant influence on the regeneration density of all three oak species. ANOVA of oak regeneration density by the stand scale factors showed that stand slope position combined with stand aspect had a significant influence on regeneration density of all three oak species. Aspect and slope position were two most important abotic factors in oak regeneration because they not only represented stand's physiography, but also reflected soil, moisture, and light conditions of the stand (Finney and others 1962, Kercher and Goldstein 1977, Standiford and others 1997).

Similar to former research results (McCarthy and others 1984, Seischab 1985), the distribution of regeneration by stand aspect showed that stands with northern aspects had the lowest regeneration density for all three oaks in both time periods except white oak after harvest (table 1). Regeneration densities of chestnut oak on the northern aspects were significantly lower than the other aspects.

The distribution of regeneration by slope position (table 2) showed that white oak advance regeneration appeared to be favored by flat slope position (i.e., ridges and bottoms), while chestnut oak appeared to be favored by upper slope locations. Northern red oak regeneration did not differ significantly among slope positions. Red maple had the most abundant regeneration density across the whole region, and it regenerated best on northern aspects and on benches.

At the 20th-acre plot level, exposure angle and slope shape were two of the most important factors affecting oak regeneration. In all cases, small exposure angle limited oak regeneration

Table 1.—*Regeneration density (stems/acre) versus stand aspect*

Stand	Red maple		White oak		Chestnut oak		Northern red oak		Total oak	
aspect	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-	Pre-	Post-
N (6,5)*	24999 a**	10137 a	790 a	1660 a	1533 a	2071 a	961 a	412 a	3284 a	4143 a
E (7,2)	22383 a	10165 a	945 a	2490 a	3753 b	5198 b	3189 a	2245 a	7887 b	9933 b
S (15,8)	21129 a	16171 a	1602 a	615 a	3814 b	5895 b	1893 a	1162 a	7309 b	7672 b
W (8,3)	18458 a	15196 a	3384 a	183 a	5889 b	4743 b	1910 a	1592 a	11183 c	6518 b

* Number of stands that have this stand aspect before and after harvest.
** Mean densities within the same column not sharing same letters are significantly different at $P < 0.05$.

Table 2.—*Regeneration density (stems/acre) versus slope position*

Slope position	Red maple Pre-	Red maple Post-	White oak Pre-	White oak Post-	Chestnut oak Pre-	Chestnut oak Post-	Northern red oak Pre-	Northern red oak Post-	Total oak Pre-	Total oak Post-
Ridge (6, 2)*	24601 a**	24144 a	6459 a	162 a	4423 a	2176 a	2882 a	1233 a	13764 a	3571 a
Upper slope (6, 3)	20510 a	10379 a	325 b	—	7096 b	9693 b	1320 a	1836 a	8741 ab	11529 b
Mid slope (9, 5)	22480 a	13182 a	702 b	1576 a	2570 a	5712 a	1573 a	689 a	4845 b	7977 a
Lower slope (8, 8)	12280 a	12632 a	539 b	982 a	3098 a	2779 a	1937 a	1151 a	5574 b	4912 a
Bench (2, 0)	57600 b	—	611 b	—	3208 a	—	1405 a	—	5224 b	—
Plateau (5, 0)	17057 a	—	—	—	—	—	4691 a	—	4691 b	—
Bottom (2, 0)	19800 a	—	4584 a	—	4508 a	—	1421 a	—	10513 ab	—

* Number of stands that have this slope position before and after harvest.
* Mean densities within the same column not sharing same letters are significantly different at P < 0.05.

density (figs. 1 to 3). Alternatively, presumably because of other limiting factors, large exposure angle did not always mean high density of oak regeneration. But if other factors were not limiting, both white oak and northern red oak had optimum exposure angles over 140 degrees for advanced regeneration (figs. 1 and 3), while chestnut oak had optimum exposure angles over 110 degrees (fig. 2). It appears that the minimum exposure angle for abundant regeneration may be lower for chestnut oak than for white oak and northern red oak.

As illustrated by figures 4 through 6, all oaks had the most abundant regeneration with near linear slope shape, and had the lowest density either with extreme concave or convex shapes. Regeneration abundance declined abruptly as slopes became noticeably concave or convex. Exposure angle and slope shape had the similar affects on post-harvest regeneration abundance.

Neither micro-topography nor distance to the closest tree and largest canopy tree showed significant influences on oak regeneration, but there were strong relationships between regeneration and the species of the closest or largest canopy tree. Not surprisingly, the three oak species had the most abundant regeneration density when the closest or largest canopy trees were of their own species (table 3). White oak was only marginally more abundant when the closest tree was white oak as opposed to black gum (*Nyssa sylvatica* Marsh), but otherwise regeneration density was approximately doubled or tripled when the closest tree species is of its own kind. Pignut hickory (*Carya glabra* Sweet), also, tended to be associated with high oak regeneration. On the other hand, sweet birch as a closest tree species in the canopy was constantly associated with poor oak regeneration. The relationships between regeneration density and largest canopy tree were similar.

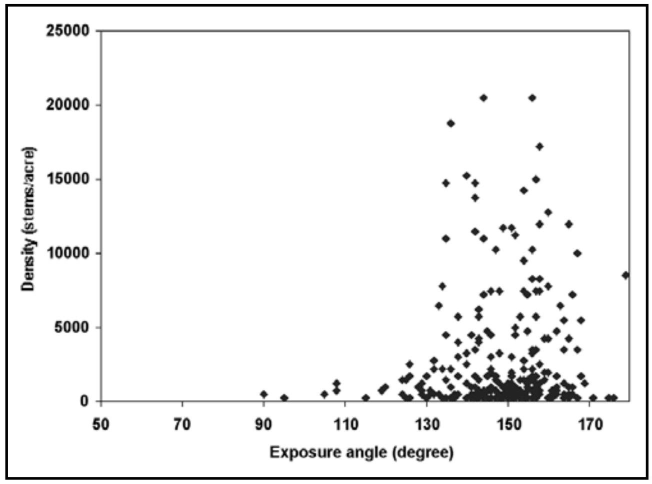

Figure 1.—*Density of advanced regeneration of white oak (stems/acre) versus plot exposure angle at plot level (only plots with at least one white oak seedling were included, n=272).*

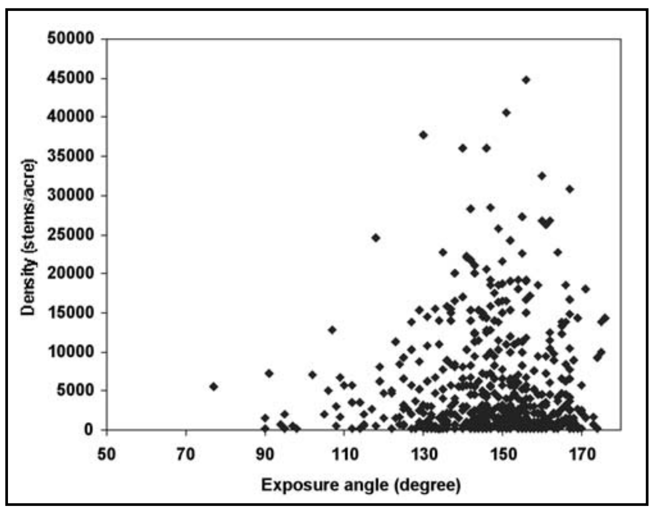

Figure 2.—*Density of advanced regeneration of chestnut oak (stems/acre) versus plot exposure angle at plot level (only plots with at least one chestnut oak seedling were included, n=558).*

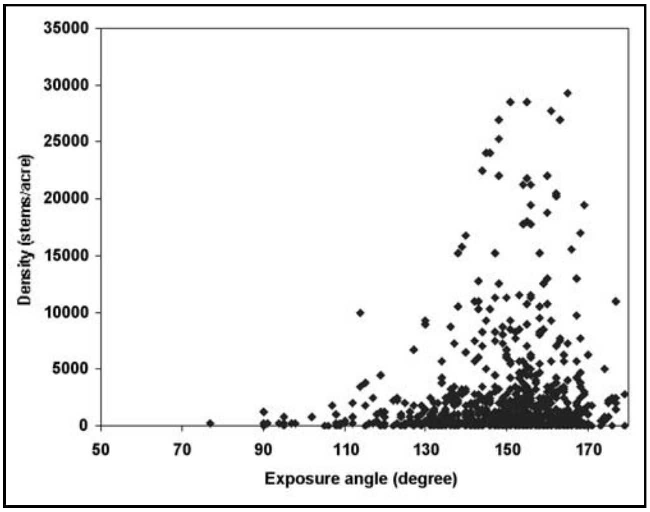

Figure 3.—*Density of advanced regeneration of northern red oak (stems/acre) versus plot exposure angle at plot level (only plots with at least one northern red oak seedling were included, n=710).*

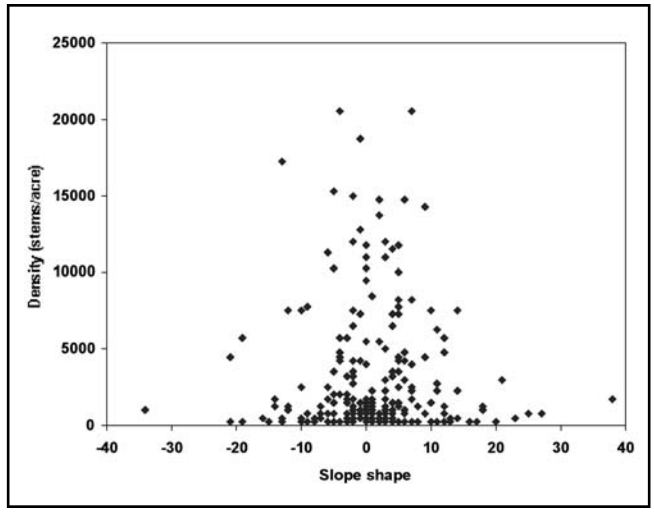

Figure 4.—*Density of advanced regeneration of white oak (stems/acre) versus slope shape at plot level (only plots with at least one white oak seedling were included, n=272).*

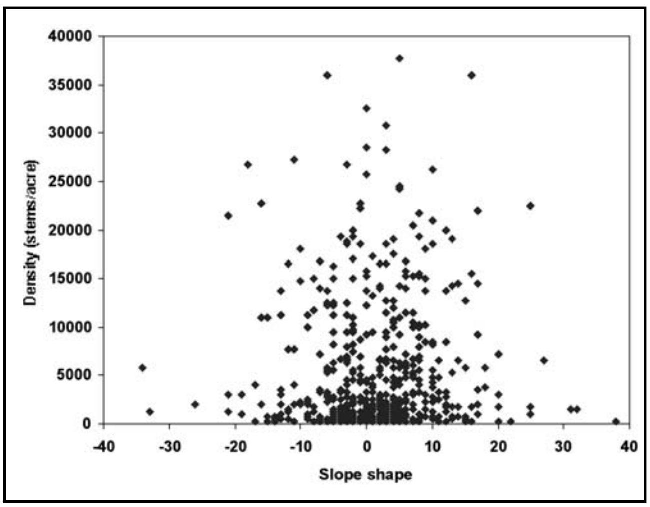

Figure 5.—Density of advanced regeneration of chestnut oak (stems/acre) versus slope shape at plot level (only plots with at least one chestnut oak seedling were included, n=558).

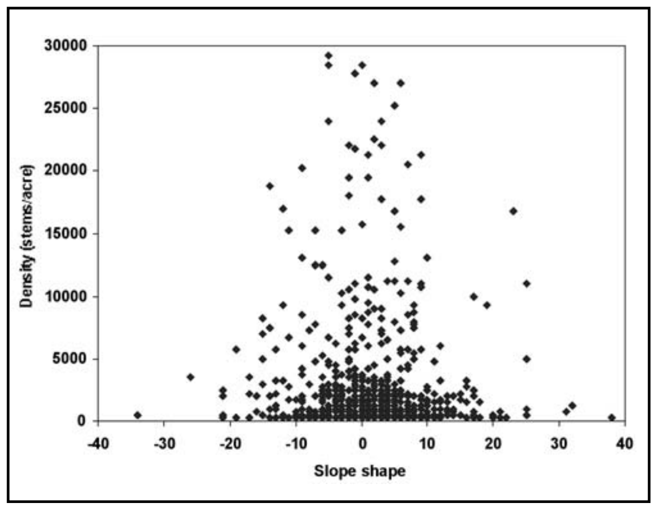

Figure 6.—*Density of advanced regeneration of northern red oak (stems/acre) versus slope shape at plot level (only plots with at least one northern red oak seedling were included, n=710).*

Table 3.— *Advanced oak regeneration density versus closest tree species to subplot.*

White oak		Chestnut oak		Northern red oak	
Closest tree species	Density (stems/acre)	Closest tree species	Density (stems/acre)	Closest tree species	Density (stems/acre)
White oak	5,692 a*	Chestnut oak	9,096 a	Northern red oak	6,349 a
Black gum	4,824 a	Black oak	4,010 b	Pignut hickory	1,944 b
Red maple	2,690 b	Pignut hickory	3,783 b	Black oak	1,811 b
Pignut hickory	2,125 b	Black gum	3,591 b	Scarlet oak	1,667 b
White pine	2,125 b	Tulip tree	3,571 b	Red maple	1,620 b
Black oak	1,818 b	Northern red oak	3,339 b	White oak	1,413 b
Scarlet oak	1,202 bc	Scarlet oak	3,066 b	White pine	1,148 bc
Chestnut oak	1,151 bc	Red maple	2,994 b	Chestnut oak	1,118 bc
Northern red oak	911 bc	White oak	2,595 b	Black gum	618 c
Sweet birch	429 c	White pine	2,438 b	Tulip tree	577 c
Tulip tree	143 c	Sweet birch	694 c	Sweet birch	528 c

* Mean densities within the same column not sharing same letters are significantly different at $P < 0.05$.

The following are our conclusions:

- In Pennsylvania, slope position together with the stand aspect were the most important factors influencing oak regeneration.
- Exposure angle (open sky between visible eastern and western horizon) was influential on oak regeneration. Large exposure angles did not appear to inhibit oak regeneration. However, small angles did, and this lower limit appeared to vary among species. Different oaks had different optimum exposure angles. The optimum exposure angles for white oak and northern red oak were over 140 degrees, while for chestnut oak the optimum was over 110 degrees.
- Linear or only slightly convex or concave slope shapes appeared to favor oak regeneration.
- There were significant relationships between the species of closest or largest canopy tree over subplots and the abundance of oak regeneration. Not surprisingly, oak regeneration was strongly favored by the presence of the same species in the canopy above the plot. The presence of pignut hickory as the closest tree species also favored oak regeneration, while regeneration was the lowest when the closest tree was sweet birch.

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