THE POST-HARVEST COMPETITIVE ENVIRONMENT IN 13 MIXED-OAK STANDS IN PENNSYLVANIA

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Abstract.—The post-harvest competitive environment in 13 mixed-oak stands in Pennsylvania was characterized using data from a repeated-measurement study. Competitors were defined as the tallest non-oaks that fell within milacre plots. Red maple was the most common competitor one and four years after overstory treatments on both high and low quality sites. Species that experienced rapid early growth became more common competitors after overstory treatments, accounting for about one-third of the competitors on high quality sites. The mean and median heights of competitors four years after treatment were 5.2 ft and 4.5 ft, respectively, on low quality sites, and 4.7 and 3.5 ft, respectively, on high quality sites. The percentage of oaks that remained competitive (oak height ≥ non-oak height) declined on high quality sites, probably due to initially small advance oak regeneration. In total, the competitive environment in Pennsylvania appears to be less severe than that reported for other regions, suggesting that large stems of advance oak regeneration may not always be necessary to regenerate oak stands in this part of the Central Hardwood region.

Introduction

The recognition of an oak regeneration problem in the eastern United States has motivated forest managers to focus on obtaining adequate advance oak regeneration before harvesting oak stands (Lorimer 1993). The pursuit of adequate regeneration begs the question of what is "adequate." In a general sense, adequate regeneration describes a population of seedlings that has a high likelihood of capturing a desirable portion of the growing space made available by an overstory removal (Larsen and Johnson 1998). An important factor influencing the amount of growing space captured by oaks is their ability to compete with other species after harvest. It is generally understood that oaks must grow at least as fast as neighboring trees to remain competitive. Consequently, the height growth of competing trees plays an important role in determining the post-harvest competitive environment.

Several influential works have engendered the belief that oaks experience a uniformly severe post-harvest competitive environment (Sander 1972; Sander et al. 1984; Loftis 1990). As a result, it is often assumed that advance oak regeneration must be large (e.g., ≥ 4.5 ft) and grow rapidly to compete after harvest (Sander 1972). While this assumption appears valid on productive sites where oaks must compete with fast-growing associates, the importance of rapid early growth is less clear on the moderately productive sites that are common in Pennsylvania and other parts of the Central Hardwood region. Others have demonstrated that modest growth rates can lead to oak regeneration success in environments with low levels of competition (Johnson et al. 1989).

The purpose of this paper is to characterize the post-harvest competitive environment in mixed-oak stands in Pennsylvania. Three questions are addressed: 1) Which species commonly compete with oaks after an overstory removal, and do these species have the potential to exclude oaks during early stand development? 2) Does the competitive status of oak regeneration generally improve, decline, or remain stable after an overstory removal? 3) What rate of post-harvest growth is required for oaks to remain competitive after harvest?

Methods

Data were collected in 13 mixed-oak stands as part of a repeated-measurement study focused on regeneration success on State Forest lands in Pennsylvania. Stand descriptions are given in Table 1.

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Table 1.—Description of the 13 stands included in the study. Site classes are site index < 70 (low) and site index ≥ 70 (high).

Stand	Site Class	Mean DBH (in)	Basal Area (ft^2) Pre-Harvest	Basal Area (ft^2) Post-Harvest	% BA in Oak	Dominant *Quercus* Species
9601	Low	9.4	93	22	89	*Q. prinus*
9701	Low	7.6	90	27	76	*Q. rubra – Q. prinus*
9706	Low	10.1	112	19	82	*Q. rubra*
9717	Low	7.2	82	18	73	*Q. prinus – Q. velutina*
9806	Low	7.6	120	6	91	*Q. prinus – Q. velutina*
9603	High	8.3	108	27	78	*Q. rubra*
9604	High	7.3	110	35	60	*Q. prinus*
9607	High	6.6	93	11	78	*Q. prinus – Q. alba*
9612	High	7.3	106	13	80	*Q. prinus – Q. coccinea*
9711	High	5.8	77	16	55	*Q. prinus*
9715	High	5.5	105	19	53	*Q. rubra – Q. prinus*
9716	High	6.9	79	15	70	*Q. prinus – Q. rubra*
9804	High	6.4	108	17	73	*Q. prinus*

Eleven of the 13 stands are located in the Ridge and Valley physiographic province, while the other two (stands 9706 and 9711) are located in the Appalachian Plateaus province. Harvests removed from 70 to 95 percent of the stands' initial basal area.

Permanent plots were established in each stand before harvest. Plots were placed on regular grids, with plot centers falling at least 209 ft apart. Within each plot, four circular milacre (43.56 ft^2) subplots were established 16.5 ft from plot center along the N, E, S, and W azimuths. Regeneration data were collected in the subplots. In total 1,291 plots were measured approximately one year before harvest, and remeasured one year and four years after harvest (each plot was measured three times).

Although a great deal of data were collected on each subplot, this paper focuses on the dominant (tallest) oak and non-oak regeneration. Hypothetically, these stems have the best chance of occupying the milacre subplot as the new stand develops. During the 1999 – 2003 field seasons, the dominant oak and non-oak were identified in each subplot and the species and heights were recorded. During the 1996-1998 field seasons, only a single dominant stem was measured and the species recorded. The missing data (either dominant oak or non-oak) were reconstructed from tallies of all regeneration by species and height class. Height classes were in 1 ft, or smaller, increments (smaller increments were used for stems < 1ft), which allowed heights to be reconstructed to the nearest foot. If only a single oak or non-oak (other than the dominant seedling) occupied the largest height class, this species was selected to augment the existing data. In cases where more than one species occupied the largest height class, the more abundant species was selected. Ties were broken at random.

For data analysis, stands were assigned to either a "low quality" class (site index < 70) or a "high quality" class (site index ≥ 70) and data in each class were analyzed separately. The high quality class included 765 plots and the low quality class included 526 plots. Six of the thirteen stands were fenced after harvest to exclude white-tailed deer (*Odocolieus virginianus* Boddaert). Data from fenced and unfenced stands were not analyzed separately because stand were fenced only if deer browsing was perceived to present a regeneration problem, and initial analysis failed to show significant differences between fenced and unfenced stands.

The composition of non-oak competitors was summarized for each period (pre-harvest, 1-yr post, and 4-yrs post) by calculating the frequency of occurrence, mean height, and median height of common non-oak species. The frequency of occurrence, mean height, and median heights of dominant oaks were also calculated. The competitive position of oaks was examined by tabulating, by period, the difference in height between dominant oaks and dominant non-oaks. The height growth required for oaks to

Table 2.—Frequency of occurrence, mean height, and median height of oaks and common competitors before and after overstory treatments on low quality sites.

Period	Species	Frequency (percent)	Height (ft) Mean	Median
Pre-Harvest	Oaks	78.3	0.9	0.8
	All Competitors	93.0	1.4	0.5
	Acer rubrum	78.0	1.3	0.5
	Acer pennsylvanicum	3.6	3.6	2.5
	Carya glabra	3.0	2.2	0.6
	Amelanchier spp.	2.4	0.9	0.8
	Pinus strobes	1.5	2.2	2.0
1-yr Post	Oaks	83.9	2.2	1.5
	All Competitors	86.4	2.0	1.5
	Acer rubrum	67.7	2.2	1.5
	Nyssa sylvatica	2.4	2.0	2.5
	Prunus serotina	2.3	2.2	2.0
	A*melanchier spp.*	2.1	1.8	1.5
	Carya glabra	1.9	1.5	1.1
4-yr Post	Oaks	87.2	5.0	4.5
	All Competitors	92.0	5.2	4.5
	Acer rubrum	70.2	5.4	4.5
	Prunus serotina	3.6	5.6	6.5
	Acer pennsylvanicum	2.4	8.4	7.5
	Nyssa sylvatica	2.1	7.6	7.5
	Betula lenta	1.9	5.5	3.5

maintain a competitive position was examined by calculating the proportion of subplots where oaks were competitive (i.e., oak height ≥ non-oak height) four years after harvest for each dominant oak height class.

Results

Advanced oak regeneration occurred on 78 percent of subplots on low quality sites (Table 2). The percentage of subplots containing oak regeneration increased to 84 percent, one year after harvest, and to 87 percent, four years after harvest. Dominant oaks averaged 0.9 ft tall before harvest, and increased to 2.2 ft, one year after harvest, and 5.0 ft, four years after harvest.

On high quality sites, advanced oak regeneration occurred on 73 percent of subplots. This percentage generally remained stable one and four years after harvest (69 and 71 percent of plots, respectively). Dominant oaks averaged 1.3 ft tall before harvest, and increased to 1.6 ft, one year after harvest, and 3.2 ft, four years after harvest.

The composition of competitors changed little throughout the study period and differed little between site classes (Table 2 and Table 3). A competitor was present on nearly all of the subplots (86 – 99 percent) at all times in both site classes. Red maple (*Acer rubrum* L.) was consistently the most common competitor by a substantial margin. The occurrence of red maple as a dominant competitor on low quality sites ranged from 78 percent of subplots, before harvest, to 67 percent, one year after harvest. On high quality sites, red maple was the dominant competitor on 64 percent of subplots before harvest. This declined to approximately 50 percent of subplots one and four years after harvest.

Four years after treatment, species that experienced rapid early growth, such as black birch (*Betula lenta* L.), blackgum (*Nyssa sylvatica* Marsh.), and black locust (*Robinia pseudoacacia* L.), became more common competitors on the high quality sites (totaling 32 percent of subplots) (Table 3), but

Table 3.—Frequency of occurrence, mean height, and median height of common competitors before and after overstory treatments on high quality sites.

Period	Species	Frequency (percent)	Height (ft) Mean (std. dev.)	Median
Pre-Harvest	Oaks	72.8	1.3	0.8
	All Competitors	96.0	2.0	0.5
	Acer rubrum	63.9	1.4	0.5
	Betula lenta	6.9	4.4	1.5
	Acer pennsylvanicum	6.1	5.7	4.5
	Nyssa sylvatica	5.8	1.5	0.8
	Amelanchier spp.	4.3	1.0	0.8
1-yr Post	Oaks	69.1	1.6	1.5
	All Competitors	95.0	1.8	0.8
	Acer rubrum	49.7	1.6	0.8
	Nyssa sylvatica	18.3	2.2	1.5
	Betula lenta	8.0	2.1	0.8
	Sassafras albidum	4.8	1.1	0.8
	Robinia pseudoacacia	4.5	3.4	4.4
4-yr Post	Oaks	70.9	3.2	2.5
	All Competitors	96.5	4.7	3.5
	Acer rubrum	50.8	4.0	2.5
	Betula lenta	14.0	5.2	4.5
	Nyssa sylvatica	12.4	6.7	6.5
	Robinia pseudoacacia	5.8	8.1	8.5
	Sassafras albidum	3.1	2.2	1.5

remained less common on the low quality sites (4 percent) (Table 2). Black cherry (*Prunus serotina* Ehrh.), which also experienced rapid early height growth, appeared among the common competitors on the low quality sites (4 percent).

The mean and median heights of competitors differed little between site classes (Table 2 and Table 3). The mean pre-harvest height was somewhat greater on the high quality sites versus low quality sites (2.0 ft versus 1.4 ft, P = 0.001 for two sample t-test), but differences between mean heights were not statistically significant one and four years after harvest. On high quality sites, the pre-treatment mean and median competitor heights were 2.0 ft and 0.5 ft, respectively. These heights remained almost unchanged one year after treatment. Four years after treatment, the mean competitor height reached 4.7 ft, with a median height of 3.5 ft. A similar pattern occurred on low quality sites, and four years after treatment the mean competitor height reached 5.2 ft, with a median height of 4.5 ft.

The competitive status of oaks remained stable on low quality sites (Table 4), but declined on high quality sites (Table 5). On low quality sites, dominant oaks were taller on approximately 40 percent of subplots throughout the study period. On high quality sites, the percentage of subplots where dominant oaks were taller decreased from 43 percent before harvest to 26 percent, four years after harvest. The percentage of plots where dominant competitors were taller increased on both high and low quality sites. Four years after harvest, dominant oaks and competitors were equal in height on a sizable percentage of subplots (about 15 percent on both high and low quality sites).

Figure 1 illustrates the percentage of dominant oaks that were competitive four years after harvest, by height class. There is little difference in the general trend between high and low quality sites. In both cases, there was a rapid increase in the percentage of competitive oaks with increasing height from 0.5 to 2.5 ft. Oaks > 3 ft were generally competitive on at least 50 percent of subplots. Oaks in the largest size class (>7 ft), were competitive on over 80 percent of subplots.

Table 4.—Distribution of height differences between dominant oaks and dominant competitors on low quality site.

Period	Oak Taller	Oak = Competitor	Competitor Taller
		— Percentage of Subplots —	
Pre-Harvest	39.2	29.4	31.4
1-yr Post	44.8	20.8	34.4
4-yr Post	39.1	15.1	45.9

Table 5.—Distribution of height differences between dominant oaks and dominant competitors on high quality site.

Period	Oak Taller	Oak = Competitor	Competitor Taller
		— Percentage of Subplots —	
Pre-Harvest	43.2	9.5	47.3
1-yr Post	39.3	18.0	42.7
4-yr Post	26.7	14.7	58.7

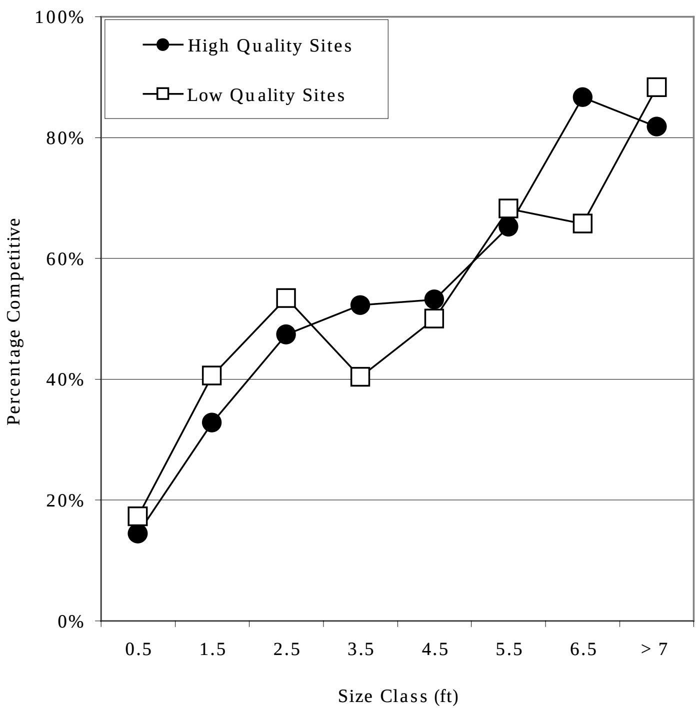

Figure 1.—Percentage of dominant oaks that remained competitive (oak height ≥ non-oak height) four years after harvest, by size class.

Discussion

Our results suggest that the influence of competition on oak regeneration success may not be as great in some Pennsylvania stands as has been reported elsewhere. Although non-oak competitors were almost always present before harvest, they were generally small, averaging only 2.0 ft on high quality sites and 1.3 ft on low quality sites. The median competitor heights are also important to consider, since early competition is most likely to occur between trees sharing the same subplot. Before harvest, dominant competitors were ≤ 0.5 ft tall on one-half of subplots on both high and low quality sites. The small competitor sizes support the conclusions of others (McWilliams et al. 1995; McWilliams et al. 2002) that the condition of advance regeneration in Pennsylvania is generally depauperate.

Although the growth rate of oaks was not high, the percentage of subplots with oak regeneration did not decline after harvest on either high or low quality sites. Four years after harvest, oaks averaged only 5 ft tall on low quality sites and were smaller on high quality sites. However, dominant competitors were not much larger, averaging 5.2 ft on low quality sites, and 4.7 ft on high quality sites. Oaks experienced some loss of competitive position harvest on high quality sites, while their competitive position remained stable on low quality sites. The loss of competitive position on high quality sites appears to be the result of poor oak growth, rather than greater competitor growth. It is possible that advance oak regeneration was initially smaller in many subplots on high quality sites, a condition that has been reported elsewhere (Host et al. 1987). In addition, competition with non-tree vegetation may have been greater on high quality sites, slowing the growth of oak regeneration.

The composition of competitors appears favorable for the long-term success of oaks in these stands. Red maple and black birch, the two most common competitors, typically form a sub-canopy beneath oaks after the second decade of stand development (Oliver 1978). Overstory treatments did result in a shift in dominance towards species with rapid initial growth, particularly on high quality sites. However, this shift was of a much lesser magnitude than has been reported on more productive sites (Beck and Hooper 1986; Loftis 1990). Notably absent among common post-harvest competitors were species, such as yellow-poplar (*Liriodendron tulipifera* L.), that are clearly capable of sustaining height growth rates superior to those of oaks. Several common competitors (e.g., striped maple *(Acer pensylvanicum* L.) and serviceberry (*Amelanchier* spp.)) that established as advance regeneration are understory obligates, and their influence on stand development will be short-lived if other species succeed in growing past them. Consequently, most competitive exclusion of oaks by non-oaks is likely to be limited to a relatively short period following overstory removal.

The relationship between dominant oak heights and the percentage of oaks that were competitive four years after treatment suggests that a range of height growth rates may result in regeneration success. It appears plausible that some oaks that are relatively small, yet larger than any nearby competitor, will ultimately become part of the next stand. In similar stands, Ward and Stephens (1999) found oaks ranging from 5 ft to < 1ft tall before harvest reached a dominant or codominant crown position 12 yrs after harvest. Small oak seedlings have generally been discounted as a source of regeneration and are generally expected to succumb to the effects of competition. While this may happen in these stands, it remains unclear which trees would out-compete the oaks.

Conclusions

Although this study only spans a four-year period, initial results suggest that the post-harvest competitive environment in some mixed-oak stands in Pennsylvania is less severe than has been reported for other regions. With this in mind, the successful regeneration of some stands may depend more on the initial establishment and early growth of advance oak regeneration than on post-treatment competition. Oak stands surely cannot be regenerated without well-distributed advanced oak regeneration, or when competing non-tree vegetation, such as hayscented fern (*Dennstaedtia punctilobula* (Michx.) Moore), inhibits early seedling growth (Steiner and Joyce 1999). These factors, along with browsing by white-tailed deer, continue to be major impediments to oak regeneration in Pennsylvania. However, once these impediments are overcome, only modest height growth may be required for a substantial percentage of oaks to remain competitive during the years following harvest. Additional research is required to determine whether oaks will maintain their competitive position after four years, but the composition of competitors is generally favorable for the long-term success of oaks.

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