CROWN CLASS DYNAMICS OF OAKS AFTER COMMERCIAL THINNING IN WEST VIRGINIA: 30-YEAR RESULTS

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Abstract.—Commercial thinning in hardwood stands is generally applied to reduce overcrowding and to favor the development of desired residual species until the stand is mature. In mixed hardwood stands, commercial thinning also provides an opportunity to promote vigorous overstory oaks (*Quercus* spp.) that will serve as sources of acorns and advanced seedlings needed to regenerate oaks in the next stand. Forest managers need information on sustaining and increasing the number of overstory oaks at mid-rotation when the stand is still several decades from maturity. In this study, crown class dynamics of 897 northern red (*Quercus rubra*), chestnut (*Q. montana*), and scarlet (*Q. coccinea*) oaks were monitored for 30 years after commercial thinning in 53-year-old central Appalachian mixed hardwood forests. Twenty 3-acre treatment plots were included in the study, and individual trees were examined immediately after thinning in 1983 and again in 2013. Fisher's exact test was used to compare the distributions of ending canopy position for thinned and control plots. In general, thinning enhanced crown class stability and survival rates of oaks that began in the upper canopy. For oaks that began in the intermediate crown class, the transition rates to the upper canopy after thinning were 33, 25, and 0 percent for northern red oak, chestnut oak, and scarlet oak, respectively. In control plots, oaks that began in the lower canopy had greater mortality rates, and very few trees ascended to the upper canopy. Forest managers can use this information to plan mid-rotation thinning treatments to enhance upper canopy species composition in the latter stages of stand development.

INTRODUCTION

If an adequate seed source is present in a mature oak (*Quercus* spp.) stand, the forest manager at least has the basic resource needed to regenerate and sustain oak species in the next stand. With careful management of seedling cohorts that result from periodic acorn crops, the forest manager can promote advanced reproduction that is large enough and abundant enough to compete successfully once the new stand develops (Dey 2014). For example, decades of research has shown that successful oak regeneration depends on the presence of competitive oak seedlings, sprout sources, or both at the time of a stand-replacing disturbance (Loftis 2004). In most cases, preparatory treatments are needed to develop competitive seedlings by focusing on the oak regeneration process 10 to 20 years before a final overstory harvest (Brose et al. 2008). These preparatory treatments include shelterwood methods to manage sunlight levels, herbicides and prescribed fires to control interfering plants, and other measures to mitigate deer browsing impact. All of these treatments focus on enhancing the growth and survival of advanced oak seedlings in preparation for an overstory harvest. Once an adequate cohort of competitive advanced oak seedlings is present, the forest manger has a reasonable assurance that oak will compete successfully in the next stand. It follows that sustaining or restoring oak

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species composition in mixed hardwood stands depends on the presence of acorn-producing trees 10 to 20 years before overstory trees are removed.

What can the forest manager do to restore an adequate oak seed source if the seed source has been depleted by previous harvests? What can the forest manager do to enhance a marginal seed source that may or may not produce enough acorns and seedlings to even begin the regeneration process described above? More attention is needed on the difficult task of enhancing the number and vigor of upper canopy oaks that are present several decades before the regeneration process begins. Commercial thinning at mid-rotation provides an opportunity to restore and promote vigorous overstory oaks that will later serve as seed trees and sources of advanced seedlings necessary to regenerate oaks in the next stand. Thinning treatments provide individual oaks with a partial or full crown release, thus allowing for faster growth, crown expansion, and increased vigor. In some cases, the crown release allows subordinate oaks to ascend to the upper canopy where over time they can become the vigorous seed trees needed for abundant acorn crops in the future.

This report describes crown class dynamics of 897 northern red (*Q. rubra*), chestnut (*Q. montana*), and scarlet (*Q. coccinea*) oaks that were monitored for 30 years after commercial thinning in 53-year-old central Appalachian mixed hardwood forests in West Virginia. Forest managers may find this information useful as they prepare mixed hardwood stands at mid-rotation to produce more abundant acorn crops many years later near the end of the rotation. Without mid-rotation thinning, subordinate oaks tend to remain so. Ward and Stevens (1994) reported 60-year crown class dynamics for northern red oaks beginning at age 25 in stands where thinning was not applied, and they found that oaks in the lower canopy exhibited greater mortality and crown class regression than those in the upper canopy. Crown release, a benefit of applying thinning treatments to individual trees, increases the probability of oaks reaching and persisting in a dominant or codominant crown class, with response varying depending on their initial crown class and competitive status (Miller et al. 2007, Rentch et al. 2009). Perkey et al. (2011) reported that growth and crown expansion of codominant oaks was related to the degree of crown release over a 20-year period. More important, within the long-term strategy of preparing stands to produce more acorns, there is a positive relationship between canopy position and the capacity of individual oaks to maintain vigor, grow faster, and produce more abundant acorn crops (Healy 1997, Johnson et al. 2009, Trimble 1969). In short, vigorous oaks in the upper canopy produce more acorns than those in the lower canopy. Crown class dynamics reported here provide the forest manger with a basis for predicting the benefits of thinning in terms of retaining oaks in the upper canopy and stimulating oaks in the lower canopy to ascend to the upper canopy where they can become better seed producers.

STUDY SITE

The study area is a second-growth mixed hardwood forest located on the West Virginia University Research Forest, near Morgantown, WV. The overstory composition included yellow-poplar (*Liriodendron tulipifera*), northern red oak, chestnut oak, white oak (*Q. alba*), red maple (*Acer rubrum*), and black cherry (*Prunus serotina*). The species composition was typical of the mixed mesophytic forest described by Braun (1950), with a site index of 75 feet for northern red oak, base age 50 years. Elevation on the study site averaged 2,100 feet, and annual precipitation averages 51 inches and is evenly distributed throughout the year (Carvell 1983). Soils are characterized as Dekalb series (loamy-skeletal, mixed, mesic Typic Dystrochrept) which are moderately deep, well-drained soils of low natural fertility on slopes and ridgetops (Soil Conservation Service 1959). The forest in the study area had its origin in 1930 after heavy logging for charcoal and lumber, thus producing an even-aged stand that was 53 years old when this study was installed.

METHODS

Twenty 3-acre square treatment plots were established in 1982 (Brock et al. 1986). A ½-acre square measurement plot was established within each treatment plot, thus allowing for a similarly treated buffer area around each measurement plot. Five plots were randomly assigned to each of three thinning treatments and a control. The treatments represented light, medium, and heavy thinning defined as 75, 60, and 45 percent residual relative density (RD) as defined by Gingrich (1967). The treatments were a form of crown thinning described by Smith (1962), with removals distributed to release desirable intermediate and upper canopy trees by removing low vigor and low value species until the desired residual density was reached. The residual stand generally included crop trees containing high-quality wood products of preferred species such as yellow-poplar, northern red oak, and black cherry. All trees within the ½-acre measurement plots were assessed before and immediately after commercial thinning in the spring of 1983. Initial crown class for each tree was defined as the crown class observed in 1983 when the stand was being marked for treatment prior to thinning. Subsequent survival and crown class assessments took place in 1993, 2003, and 2013.

Crown class was based on definitions proposed by Smith (1962). Dominant trees have crowns that rise above the general canopy and receive full light from above and partial light from the sides. Codominant trees have crowns in the upper canopy but are largely blocked by neighboring crowns from receiving light from the sides. Intermediate crowns receive a little light from above and no light from the sides, and suppressed trees have completely overtopped crowns and receive only diffuse light beneath the overstory.

Crown class transition rates were analyzed for northern red oak, chestnut oak, and scarlet oak located in thinned and control plots. Each tree was assigned an initial crown class and was then assigned to one of three outcomes at the end of the 30-year study: upper canopy (dominant or codominant), lower canopy (intermediate or suppressed), or dead. Count data from initial crown class to one of the three outcomes were converted to transition rates, defined as the proportion of trees in a given initial crown class that finished in the upper canopy, lower canopy, or died at the end of the study period. The distribution of outcomes among treatments was compared using Fisher's exact test (SYSTAT 2008). For each species and initial crown class, the distribution of outcomes in control plots was compared to that found in all thinning levels combined, followed by pairwise comparisons among the three thinning levels. The significance level for comparisons was $\alpha = 0.05$.

RESULTS

Crown class changes of residual oaks in this study were examined after 20 years and results are reported in Rentch et al. (2009). The 30-year results reported here exhibit similar trends, although in control plots the fate of oaks has gotten worse in the third decade for all species and all initial crown classes. As the untreated stand aged from 73 to 83 years, a few dominant and codominant oaks slipped to the lower canopy, and mortality continued among the intermediate and suppressed oaks. In the thinned plots, upper canopy oaks were relatively stable in the third decade, while those in the lower canopy suffered additional mortality. Canopy gaps created by the removal of merchantable trees in the thinning treatments were present for 15 to 20 years after thinning, gradually closing as the crowns of the residual trees expanded. Most canopy gaps in the thinned plots had closed by the 20^{th} year, thus the increasingly dense overhead canopy continued to have a negative impact on the shorter, lower canopy oaks during the final decade.

Response of Upper Canopy Oaks

There was no significant difference in the response of dominant trees in thinned plots compared to those in control plots. For northern red oaks, more than 90 percent of dominant trees remained in the upper canopy, only one tree died after thinning, and two trees in control plots slipped to an intermediate crown class (Table 1). For chestnut oaks (Table 2) and scarlet oaks (Table 3), more than 65 percent of dominant trees remained in the upper canopy in both thinned and control plots.

Thinning significantly improved both survival and crown class stability of codominant trees for all three oak species (Tables 1-3). In thinned plots, only 15 percent of codominant northern red oaks descended to the lower canopy or died, while 85 percent remained in the upper canopy. In control plots, 45 percent of codominant northern red oaks descended to the lower canopy or died. Chestnut oaks and scarlet oaks exhibited similar responses to thinning. In control plots, about 80 percent of codominant chestnut oaks and scarlet oaks descended to the lower canopy

Table 1.—Thirty-year crown class transition rates for northern red oaks in a 53-year-old central Appalachian hardwood stand after thinning

				30-year canopy status				
Initial crown class	Initial canopy status	Treatment	n	Upper canopy	Lower canopy	Dead	Pairwise comparisons[a]	
				---------------- percent ----------------				
Dominant	Upper	Control	28	93	7	0	a	a
		75% RD[b]	10	100	0	0	a	
		60% RD	12	92	0	8	a	
		45% RD	3	100	0	0	a	
		Thinned[c]	25	96	0	4		a
Codominant	Upper	Control	49	55	27	18	a	a
		75% RD	39	85	5	10	b	
		60% RD	31	77	13	10	ab	
		45% RD	36	92	3	5	b	
		Thinned	106	85	7	8		b
Intermediate	Lower	Control	34	0	32	68	a	a
		75% RD	30	17	50	33	ab	
		60% RD	20	45	45	10	b	
		45% RD	10	60	20	20	b	
		Thinned	60	33	44	23		b
Suppressed	Lower	Control	99	0	29	71	a	a
		75% RD	38	0	29	71	ab	
		60% RD	36	0	58	42	b	
		45% RD	7	0	43	57	ab	
		Thinned	81	0	43	57		b

[a] For pairwise comparisons within each category of initial crown class, rows with different letters are significantly different from expected values.
[b] RD=relative density
[c] All thinned combined.

or died, while about 20 percent remained in the upper canopy. In thinned plots, 79 percent of codominant chestnut oaks and 67 percent of codominant scarlet oaks remained in the upper canopy 30 years after thinning.

Response of Lower Canopy Oaks

Among oaks in the suppressed crown class, thinning generally increased their survival (Tables 1-3). In control plots, more than 70 percent of suppressed oaks died during the study. Mortality dropped to 57 percent for northern red oaks and 32 percent for chestnut oaks in thinned plots. The sample size for suppressed scarlet oaks was too small to draw any meaningful conclusions; two trees in a control plot died, while one tree in a thinned plot survived. Of 256 suppressed oaks observed in this study, none ascended to the upper canopy in either thinned or control plots after 30 years.

Table 2.—Thirty-year crown class transition rates for chestnut oaks in a 53-year-old central Appalachian hardwood stand after thinning

				30-year canopy status				
Initial crown class	Initial canopy status	Treatment	n	Upper canopy	Lower canopy	Dead	Pairwise comparisons[a]	
				---------------- percent ----------------				
Dominant	Upper	Control	14	71	29	0	a	a
		75% RD[b]	5	80	20	0	a	
		60% RD	5	80	0	20	a	
		45% RD	9	78	22	0	a	
		Thinned[c]	19	79	16	5		a
Codominant	Upper	Control	45	20	53	27	a	a
		75% RD	34	79	21	0	b	
		60% RD	18	94	6	0	c	
		45% RD	25	68	20	12	c	
		Thinned	77	79	17	4		b
Intermediate	Lower	Control	54	6	31	63	a	a
		75% RD	8	12	63	25	ab	
		60% RD	14	29	71	0	b	
		45% RD	2	50	50	12	b	
		Thinned	24	25	67	8		b
Suppressed	Lower	Control	42	0	26	74	a	a
		75% RD	12	0	67	33	b	
		60% RD	14	0	71	29	ab	
		45% RD	5	0	60	40	ab	
		Thinned	31	0	68	32		b

[a] For pairwise comparisons within each category of initial crown class, rows with different letters are significantly different from expected values.
[b] RD=relative density.
[c] All thinned combined.

Thinning increased survival of oaks in the intermediate crown class as well. In control plots, mortality was 68, 63, and 89 percent of intermediate northern red oaks, chestnut oaks, and scarlet oaks, respectively (Tables 1-3). In thinned plots, mortality of intermediate oaks was less than 25 percent for all three species. One of the key benefits of thinning oak stands at mid-rotation is the opportunity to increase the number of upper canopy oaks, primarily by stimulating intermediate oaks to ascend to codominant status. None of the intermediate northern red oaks or scarlet oaks ascended to codominant status in control plots, and only 3 of 54 chestnut oaks moved up in control plots. In thinned plots, 33 percent of northern red oaks and 25 percent of chestnut oaks ascended from intermediate to codominant status after 30 years. Among the northern red oaks that moved to the upper canopy, 65 percent did so within the first 10 years after thinning, 20 percent moved up in the second decade after thinning, and another 15 percent moved up in the third decade. Among the chestnut oaks that moved to the upper canopy, 83 percent did so in the first 10 years after thinning, the remaining 17 percent moved up in the second decade, and no chestnut oaks moved up in the third decade. None of the intermediate scarlet oaks ascended to codominant status in the thinned plots; however, the sample size was relatively small.

Table 3.—Thirty-year crown class transition rates for scarlet oaks in a 53-year-old central Appalachian hardwood stand after thinning

Initial crown class	Initial canopy status	Treatment	n	30-year canopy status: Upper canopy	Lower canopy	Dead	Pairwise comparisons[a]	
				-------- percent --------				
Dominant	Upper	Control	19	78	11	11	a	a
		75% RD[b]	4	50	0	50	a	
		60% RD	1	100	0	0	a	
		45% RD	7	72	14	14	a	
		Thinned[c]	12	67	8	25		a
Codominant	Upper	Control	28	18	36	46	a	a
		75% RD	30	67	23	10	b	
		60% RD	0	0	0	0		
		45% RD	3	67	0	33	b	
		Thinned	33	67	21	12		b
Intermediate	Lower	Control	9	0	11	89	a	a
		75% RD	4	0	75	25	a	
		60% RD	0	0	0	0		
		45% RD	1	0	100	0	b	
		Thinned	5	0	80	20		b
Suppressed	Lower	Control	2	0	0	100	a	a
		75% RD	1	0	100	0	b	
		60% RD	0	0	0	0		
		45% RD	0	0	0	0		
		Thinned	1	0	100	0		b

[a] For pairwise comparisons within each category of initial crown class, rows with different letters are significantly different from expected values.

[b] RD=relative density.

[c] All thinned combined.

DISCUSSION

Forest management objectives for sustaining or increasing the number of overstory oaks might include seed production for wildlife food, accumulation of seed trees for future regeneration, increasing species diversity, and enhancing high quality wood production. The basal area threshold for adequate acorn production and associated advanced oak reproduction is approximately 40 square feet per acre of overstory oaks in the mid-Atlantic region (Brose et al. 2008). Depending on the average diameter of overstory trees, forest managers need to promote 30 to 40 upper canopy oaks per acre as the stand nears maturity to assure an adequate seed source is present at the beginning of the oak regeneration process. Thinning treatments at key stages allow oaks to maintain or ascend to an upper canopy position, particularly on high-quality sites where numerous competing species exhibit faster early height growth (Dey 2014, Miller et al. 2007, Oliver 1980). Residual stand goals for the number of upper canopy oaks can guide "cut-or-leave" criteria when the stand is marked for thinning. In general, enough oaks in both upper and lower canopy positions should receive an adequate crown release after thinning to achieve the desired overstory species composition.

To apply the crown class dynamics presented here, forest managers first need a tally of both upper canopy oaks and those in the intermediate crown class. Because none of the suppressed oaks ascended to the upper canopy after thinning, they lack the potential to be reliable seed trees in the future. Suppressed oaks could be retained after thinning to serve as potential sprout sources at final harvest, but they promise little in the way of future acorns or advance seedlings during the regeneration process. If the stand contains an adequate number of upper canopy oaks before thinning, then the thinning treatment should be applied to favor their crown development and retain them in the upper canopy. In this study, retention of upper canopy status 30 years after thinning was about 90 percent for northern red oak, 80 percent for chestnut oak, and 70 percent scarlet oak. Crown class retention of codominant oaks dropped significantly in control plots. If ascension of intermediate oaks is required to achieve residual stand goals for upper canopy oaks, the thinning treatment must release several intermediate oaks in order to promote one to the upper canopy. In this study, 33 percent of intermediate northern red oaks and 25 percent of intermediate chestnut oaks ascended to the upper canopy after thinning. Marking guidelines could include "release 3 to get 1" for northern red oak and "release 4 to get 1" for chestnut oak if the thinning is planned about 30 years before final harvest. No intermediate scarlet oaks ascended to the upper canopy after thinning.

The timing of the first commercial thinning is a function of site quality and local wood markets. On relatively high quality sites, upper canopy trees may reach merchantable size classes sooner than on lower quality sites. In addition, local wood markets and general economic conditions often affect the merchantability of the relatively low volumes associated with thinning harvests. If sustaining and promoting upper canopy oaks for future acorn production is a priority, forest managers should consider applying the first thinning as early as possible in the rotation. In cases where the number of upper canopy oaks is a concern, it might be advantageous to apply a precommercial crown release to selected oaks before the first commercial thinning, thus enhancing their status until commercial operations are feasible.

Traditional silvicultural criteria should be used to decide which oaks to favor as residual trees in the upper or lower canopy. Residual trees should have relatively good vigor and full crowns with little evidence of excess branching or crown dieback. Residual oaks with good initial stem quality tend to retain good quality after a thinning treatment (Miller et al. 2008). Likewise, trees with excess branching or evidence of poor quality before thinning tend to become worse after thinning. In making cut-or-leave decisions among intermediate trees before thinning, it is recommended that preference be given to retaining oaks that exhibit better-than-average initial stem quality. Visible stem quality may indicate good genetic characteristics, as well as favorable microsite conditions, that would allow the tree to respond well to the thinning treatment.

ACKNOWLEDGMENTS

The authors thank John Juracko, Brian Simpson, Regis Young, Veronica Maxwell, Gino Luzader, Tesia Gnegy, Josh Embrey, and Cory Haas, all employees of the U.S. Forest Service, Northern Research Station in Morgantown, WV, for assistance with the 30-year data collection.

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