LONG-TERM RESPONSE OF YELLOW-POPLAR TO THINNING IN THE SOUTHERN APPALACHIAN MOUNTAINS

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Yellow-poplar (*Liriodendron tulipifera* L.) is the most abundant individual tree species (in terms of volume) in the southern Appalachian Mountains, with Forest Inventory and Analysis (FIA) reports documenting a continuous increase in yellow-poplar over the recent years (Brown 2003, Schweitzer 1999, Thompson 1998). Current management efforts in even-aged yellow-poplar stands rarely include thinning operations. However, thinning prescriptions largely driven by timber-related goals and objectives were once commonplace across the region. As a consequence of shifting objectives, these previously thinned stands, which were traditionally managed on a timber- or financially-related rotation length, are no longer actively managed within the original silvicultural prescription. Despite not being under an active management plan, these previously thinned stands may continue to respond to past treatments. As the focus of forest management on many public lands shifts away from timber production and extraction to ecosystem-based management, it is important to understand the long-term effects that previous management activities have on structure to better inform current management decisions. Because many of these stands were, in the past, harvested prior to their biological rotation age, there is limited quantitative data regarding the long-term effects of previous management activities on long-term growth patterns over time. In this paper, we analyzed 40 years of post-thinning growth data to assess the long-term response of yellow-poplar stands to thinning across a broad age and site quality gradient in the southern Appalachian Mountains.

Between 1960 and 1963, 134 plots 0.1 ha in size were established across an age and site quality gradient in yellow-poplar stands throughout the southern Appalachian Mountains. All plots were thinned from below, with post-thinning relative density ranging between 12 and 56 percent. In 2009, increment cores from five dominant/co-dominant yellow-poplar trees were obtained from all plots. Radial growth was crossdated, measured, and converted to annual basal area increment (BAI; $cm^2\ yr^{-1}$). Using plot-level BAI chronologies, average annual BAI for five time periods was calculated: (1) 10 years prior to thinning (BAI_{pre}); (2) between 1 and 10 years post-thinning (BAI_{post10}); (3) between 11 and 20 years post-thinning (BAI_{post20}); (4) between 21 and 30 years post-thinning (BAI_{post30}); and (5) between 31 and 40 years post-thinning (BAI_{post40}). Plots were classified into three density classes based on post-thinning relative density [Stand Density Index $(SDI)_{observed}/SDI_{maximum}$]: (1) low (relative density < 0.25); (2) moderate (relative density ≥ 0.25 but < 0.35); and (3) high (relative density ≥ 0.35 but < 0.60).

We used analysis of covariance (ANCOVA) to determine the effects of density (low, moderate, high), site index, average age at the time of thinning, and time since thinning (10, 20, 30, and 40 years post-thinning) on relative post-thinning BAI ($RBAI_{post}$). Relative BAI is unitless and is defined as average annual BAI_{post10}, BAI_{post20}, BAI_{post30}, and BAI_{post40} divided by BAI_{pre}. Values of $RBAI_{post} < 1.0$ signify a slow-down in growth relative to pre-thinning rates, whereas values of $RBAI_{post} > 1.0$ indicate an increase in growth.

$RBAI_{post}$ varied across time periods and density classes (table 1). During the first decade post-thinning, 92, 86, and 57 percent of plots in the low-, moderate-, and high-density classes, respectively, contained trees whose RBA_{post} values were ≥ 1.0. During that first decade post-thinning, 23 and 14 percent of the plots in low- and moderate-density classes, respectively, contained trees that experienced at least a 100 percent increase in BAI relative to pre-thinning growth rates. The proportion of plots containing trees that displayed an increase in growth

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Table 1--Percentage of plots in low (*n*=39), moderate (*n*=42), and high (*n*=53) density classes in each cumulative relative basal area increment ($RBAI_{post}$) category during the 10, 20, 30, and 40 year growth periods post-thinning

Density class	≤1.0	≥1.0	≥1.1	≥1.2	≥1.3	≥1.4	≥1.5	≥2.0	≥2.5	≥3.0
					10 years post-thinning					
Low	8	92	87	82	69	67	67	23	10	3
Moderate	14	86	81	71	64	55	45	14	0	0
High	43	57	38	25	25	15	11	0	0	0
					20 years post-thinning					
Low	5	95	92	79	77	64	56	33	10	3
Moderate	12	88	81	64	57	55	43	12	2	0
High	30	70	62	47	34	28	23	2	0	0
					30 years post-thinning					
Low	36	64	59	46	36	26	21	8	5	3
Moderate	62	38	26	17	17	14	7	0	0	0
High	72	28	17	11	8	6	4	0	0	0
					40 years post-thinning					
Low	29	71	71	68	58	47	37	5	8	3
Moderate	67	33	26	21	19	14	14	2	2	0
High	55	45	32	30	25	17	13	2	2	0

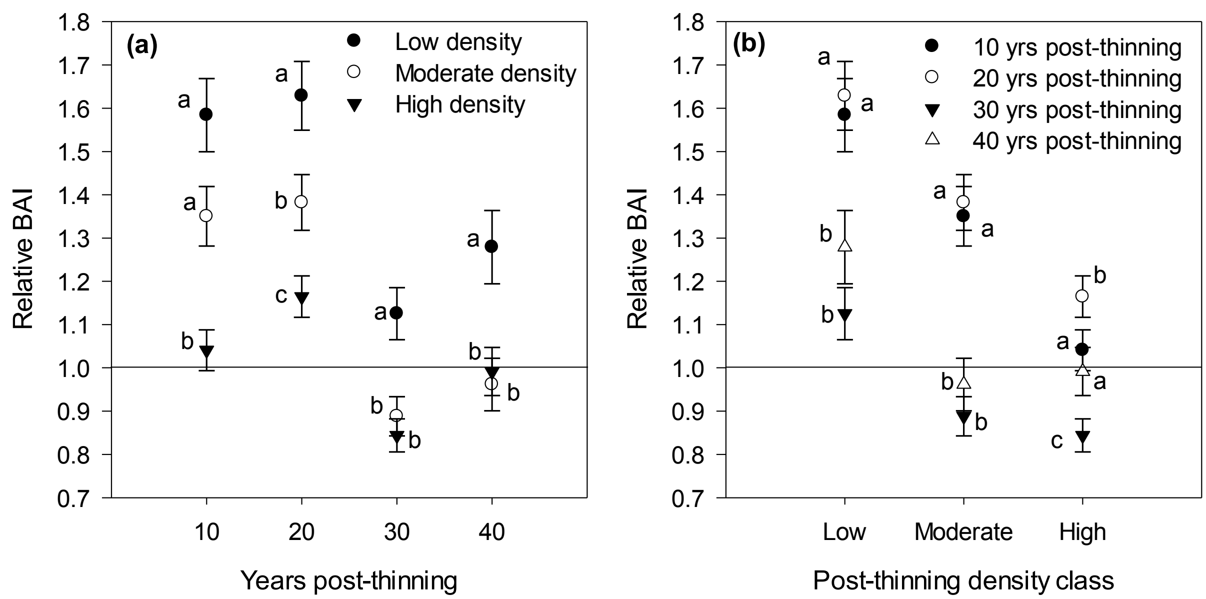

Figure 1--Post-thinning relative basal area increment ($RBAI_{post}$) among time periods within a given density class (a) and among density classes within a given time period (b). Values and error bars represent the lsmeans and standard errors, respectively at the median site index value (site index = 32.3). Lsmeans followed by the same letter are not significantly different. The solid line (y = 1) indicates no change between pre- and post-thinning BAI.

relative to pre-thinning rates generally increased between 11 and 20 years post-thinning. By the fourth decade following thinning, the sample trees in 71, 33, and 45 percent of plots in the low-, moderate-, and high-density classes, respectively, continued to experience an increase in BAI relative to pre-thinning growth rates.

Site index was a significant and positive covariate in the ANCOVA of $RBAI_{post}$, with the effects of site index similar across density classes. During the 10-year time period following thinning, the only significant differences in $RBAI_{post}$ among density classes was between the low- and high- and moderate- and high-density classes (fig. 1a). As time progressed, $RBAI_{post}$ in the low-density class continued to exceed that in the moderate- and high-density classes. In the low- and moderate-density classes, we observed no significant differences in $RBAI_{post}$ between the 10 and 20 year time periods post-thinning (fig. 1b). There was a significant decrease in $RBAI_{post}$ during the third decade post-thinning. The decline in $RBAI_{post}$ during the third decade post-thinning appears to be related to moderate drought conditions across the region during the 1980s.

It is apparent from the results presented here that intermediate silvicultural treatments can have long-lasting effects on stand structure. For yellow-poplar, the increase in tree growth at the lowest residual densities was sustained over the 40-year period encompassed by this study. As these stands approach the traditional rotation age, it is apparent that crop trees continue to benefit from previous thinnings. Beyond traditional timber objectives, the thinning conducted 40 years ago accelerated the development of large trees, a key attribute associated with mixed-mesophytic forests in the later stages (e.g., understory re-initiation and old-growth) of stand development (Greenberg and others 1997). It appears that thinning across a broad age class can accelerate tree growth in the long term, and may serve as an initial restoration treatment in these homogenous yellow-poplar stands.

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