Height Development of Upper-Canopy Trees Within Even-Aged Adirondack Northern Hardwood Stands

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ABSTRACT:

*Knowledge of the relative rates of height growth among species is necessary for predicting developmental patterns in even-aged northern hardwood stands. To quantify these relationships, we used stem analysis to reconstruct early height growth patterns of dominant and codominant sugar maple (*Acer saccharum *Marsh.), yellow birch (*Betula alleghaniensis *Britton), white ash (*Fraxinus americana *L.), and America beech (*Fagus grandifolia *Ehrh.) trees. We used three stands (aged 19, 24, and 29 years) established by shelterwood method cutting preceded by an understory herbicide treatment. We analyzed 10 trees of each species per stand. Height growth was similar across stands, allowing us to develop a single equation for each species. Our data show that yellow birch had the most rapid height growth up to approximately age 10. Both sugar maple and white ash grew more rapidly than yellow birch beyond that point. Beech consistently grew the slowest. White ash had a linear rate of height growth over the 29-year period, while the other species declined in their growth rates. By age 29, the heights of main canopy trees ranged from 38 ft for beech to 51 ft for white ash. Both yellow birch and sugar maple averaged 46 ft tall at that time. By age 29, the base of the live crown had reached 17, 20, 21, and 26 ft for beech, sugar maple, yellow birch, and white ash, respectively. Live–crown ratios of upper-canopy trees did not differ appreciably among species and remained at approximately 40% for the ages evaluated. These results suggest that eliminating advance regeneration changes the outcome of competition to favor species other than beech. North. J. Appl. For. 21(3):117–122.*

Key Words: Species height growth, early stand development, Adirondack northern hardwoods, shelterwood cutting.

Understanding patterns of natural stand development is essential when planning cultural treatments (Oliver and Larson 1996). For naturally regenerated hardwood communities, knowledge of growth rates by species allows managers to better predict the likely species composition that will develop, the patterns of height growth and radial increment, the development of clear length on surviving trees, and the proportion of basal area among species through time (Wang and Nyland 1993). Such information is essential for appropriately timing early cultural treatments to enhance crop tree development, while insuring that they grow stems of high commercial value (Sonderman 1979, Heitzman and Nyland 1991).

Crown canopy closure marks one of the important transition points in young hardwood stand development. It initiates a long period of intense inter-tree competition marked by high levels of mortality, even while the total biomass increases (Bormann and Likens 1979). Trees become vertically stratified between and within species, and radial increment begins to slow (Oliver 1981, Marquis 1991, Nyland et al. 2000). For young, even-aged northern hardwoods in central New York, canopy closure occurs within 10–15 years after a reproduction method cutting

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(Walters and Nyland 1989; Wang and Nyland 1993, 1996; Ray et al. 1999; Nyland et al. 2000). Furthermore, in stands that initially had well-developed advance regeneration, the base of the live crown reached 7–12 ft by age 10–13, and 9–22 ft by ages 17–20. Total heights measured 40–51 ft by 20 years (Wang and Nyland 1996).

Silvicultural treatment during these early stages of development opens the canopy and keeps the lower branches alive. This can slow the development of clear wood on the main stem (Sonderman 1979, Heitzman and Nyland 1991). Early intervention might also promote low forking (Heitzman and Nyland 1991). Knowing how rapidly the base of the live crown rises on a tree would allow managers to more effectively schedule early treatments to minimize the negative effects, while also ensuring timely entry to maintain radial increment at high rates. Understanding the rates of total height growth would indicate the relative positions that different species might occupy within the main crown canopy, and if early intervention (e.g., cleaning) might be necessary to insure the dominance of species that best satisfy the management objectives.

Earlier studies of height growth in northern hardwoods have focused mainly on stands having advance regeneration, primarily of shade-tolerant species. Findings reflect the influence of seedling abundance, condition, and size at the time of overstory cutting (Marquis 1967, Wang and Nyland 1996, McClure et al. 2000). For the study reported here, we sought to quantify the height growth rates of American beech, sugar maple, yellow birch, and white ash at sites where mistblowing of herbicide had controlled understory beech prior to shelterwood method seed cutting. Due to the treatment, our stands lacked advance regeneration of any species, allowing us to compare the height growth of trees that became established at the time of overstory cutting. We also quantified changes in clear length and live-crown ratios of these trees.

Methods

Study Sites

We sampled three northern hardwood stands established by shelterwood method cutting on the Huntington Wildlife Forest near the town of Newcomb in the central Adirondack Region of New York State. The study sites had supported well-developed northern hardwood communities (200–300 years old) dominated by sugar maple and beech with lesser amounts of yellow birch, white ash, and black cherry (*Prunus serotina* Ehrh.). Understory mistblowing followed by individual stem injection of larger unmerchantable trees was used to control the beech in these stands (see Kelty and Nyland 1981, Sage 1987). The treatment eliminated advance growth of all woody species and removed trees that had occupied intermediate and overtopped positions in the original stands. In addition, hunting reduced the impact of local deer populations, whose feeding habits favor the development of beech. Both treatments have proven necessary to successfully regenerate northern hardwood stands in this region (Tierson 1967, Kelty and Nyland 1981, Sage 1987).

Seed cutting left widely spaced, sawtimber-sized sugar maple trees of uppermost canopy positions (20–50% canopy cover in all stands). Removal cutting occurred 4 years after seed cutting in Stand II, and at 10 years in Stands I and III. The removal cut in Stand II was done earlier to assess the degree to which a shortened period of shelterwood influence might speed development of the new cohort. It had little effect at these sites, likely due to the low density of seed trees in all areas (Ray et al. 1999). When we sampled Stands I, II, and III they had grown for 19, 24, and 29 years, respectively, following seed cutting. A period of 9, 20, and 19 years had elapsed since overstory removal.

Data Collection

We established a 1- × 2-chain systematic grid within each stand and selected 10 grid intersections at random as starting locations for selecting trees for stem analysis. For each species, we sampled the qualifying tree closest to the chosen grid points, but in some cases returned for a second tree to insure equal representation of each species within each stand. Sampled trees occupied upper canopy positions (dominant and codominant), and had no signs of crown damage due to insects, animals, disease, or weather. We used prominent forking as the primary indicator of past damage. All together, we felled 10 upper canopy trees of each species in each stand, for a total of 120 sample trees (3 stands × 4 species × 10 trees per species per stand).

We marked and measured diameter at breast height (dbh) prior to felling and cut each stem close to ground level. After felling a tree, we measured total height and distance to the base of the first live branch. Then we sectioned the stem at 3-ft intervals up to the base of the first live branch, and recorded the distance above the ground to live foliage. Finally, we sectioned the crown portion of the main stem at 3-ft intervals.

We counted annual rings along two perpendicular radii to determine the age for each stem section, then applied Carmean's (1972) correction factor to obtain unbiased estimates of the height-age pairs. This method assumes that annual height growth is constant for each year wholly or partially contained within a stem section, and that a crosscut will occur in the middle of a year's height growth. We used the age at stump height as a surrogate for time of establishment, and as year 0 for determining the rate of height growth.

Data Analysis

To justify pooling height-age pairs for each species across stands, we used analysis of variance (ANOVA) to compare total heights among species at age 19, the latest common age for the three stands. We evaluated the main effects of species and stand, as well as their interaction. We used a means separation procedure (Fischer's Protected LSD) to identify significant differences between species for a number of measured variables: years to reach stump height, total height, dbh, clear length, and live-crown ratio (defined here as the ratio between the height to the base of live foliage and total height). All significance tests were conducted at $\alpha = 0.05$, and individual means were not separated if the overall F-test was not significant (Fischer's Protected LSD).

We used repeated-measures mixed models (Littell et al. 1996) to fit the height-age data for each species. This approach correctly evaluates the autocorrelation between stem sections within a tree, and partitions the fixed and random effects in the model. Here, species were treated as fixed effects, and stands and individual trees considered as random effects. We fitted simple linear and quadratic polynomial regression models to the data. These model forms adequately described the patterns of height growth observed for this range of data. We described the rate of growth as the first derivative of the regression equation for height as a function of age.

Results

Our ring counts indicate that sugar maple, yellow birch, and white ash reached stump height within 4 years after seed cutting. On average, beech reached stump height soonest, within 2 years (Table 1). The trees were too large at the time of sampling for us to identify their mode of origin, but this rapid early height growth is consistent with root suckering for beech.

Total heights differed significantly among species at age 19 (ANOVA $df = 3$, $P < 0.00$), but not between stands for a given species ($df = 2$, $P = 0.29$), and no species-by-stand interaction was detected ($df = 6$, $P = 0.64$). This finding justified pooling the data by stand and allowed us to develop species-specific height growth models (Table 2 and Figure 1a). Those models provided good fits for our data, as indicated by the P values and standard errors of the parameter estimates (Table 2). Quadratic terms in the height regression models were significant ($P < 0.05$) for beech, sugar maple, and yellow birch, indicating that these species were slowing in height growth within the 30 years following seed cutting. By contrast, the quadratic term was not significant for white ash, and a linear model provided a better fit to the data for this species (Figure 1a). In other words, white ash had a more sustained rate of height growth than the other species.

The average height growth rates (Figure 1b) indicate that through 8 years after seed cutting, yellow birch averaged 2.2 ft yr^{-1}. Sugar maple and white ash both grew at average rates of 1.9 ft yr^{-1}. Beech averaged 1.6 ft yr^{-1}for that same period. By approximately 25–27 years, height growth rates for beech had slowed to 1.0 ft yr^{-1}. Regression analyses indicated that the periodic height growth rates declined through time for sugar maple, yellow birch, and beech. But it declined more rapidly for yellow birch than any of the other species (Figure 1b). White ash had a fairly steady height growth rate over the 29-year period documented in this study, as indicated by the linear fit of the model.

The dbh of sample trees varied in a consistent way across stands, suggesting a consistent pattern by age as well as by species (Table 1). Yellow birch and white ash, which are intermediate in shade tolerance, had significantly larger diameters than shade-tolerant sugar maple and beech in all but the youngest stand. There, where sugar maple was similar to white ash. Beech had a smaller average diameter than any of the other species in the 29-year-old stand. The diameters for white ash and yellow birch did not differ significantly at 24 and 29 years.

White ash had the greatest clear bole length in all stands, averaging approximately 26 ft at 29 years (Table 1). Sugar maple and yellow birch both had clear lengths of around 20 ft at that time, and beech averaged approximately 17 ft. The live-crown ratios for main canopy stems did not differ significantly among species or by stand age, averaging 42% across the three sites (Table 1).

Discussion

These findings complement earlier information about shifts in numbers of stems, tree diameters, and basal area

Table 1. Characteristics of upper-canopy trees of four northern hardwood species growing in a chronosequence of relatively young shelterwood stands at the time they were harvested for detailed stem analysis.

Area	Species	Stump^{a} (yr)	Dbh (in.)	Height	Clear length	Live crown ratio^{b} (%)
				. . . .(ft)	. . . .	
Stand I—Age 19						
	Sugar maple	2.5^{a}	$2.73^{b,c}$	31.5^{b}	13.8^{a}	45
	Yellow birch	3.0^{a}	3.28^{a}	33.5^{ab}	14.4^{a}	49
	Beech	1.5^{b}	2.46^{c}	27.2^{c}	10.3^{b}	47
	White ash	2.1^{ab}	3.15^{ab}	34.9^{a}	17.2^{a}	41
Stand II—Age 24						
	Sugar maple	3.1^{a}	3.28^{b}	39.4^{b}	19.9^{b}	39
	Yellow birch	3.8^{a}	4.21^{a}	39.6^{b}	18.7^{b}	37
	Beech	1.1^{b}	3.08^{b}	35.1^{c}	17.7^{b}	35
	White ash	2.9^{a}	4.29^{a}	42.9^{a}	23.8^{a}	36
Stand III—Age 29						
	Sugar maple	2.9	4.41^{b}	46.2^{b}	19.8^{b}	45
	Yellow birch	2.1	5.65^{a}	46.0^{b}	20.9^{b}	42
	Beech	2.0	3.79^{c}	37.8^{c}	16.9^{c}	40
	White ash	2.3	5.33^{a}	50.7^{a}	25.7^{a}	40

[a] Stump indicates years to reach stump height = time since seed cutting − total age at stump height.

[b] Live crown ratio = (height to base of live foliage/total height) × 100.

NOTE: Differences are significant ($\alpha = 0.05$) between values designated by different letters (Fisher's Protected LSD).

Table 2. Regression parameters for the species specific height growth models describing the early development of four northern hardwood species of upper-canopy position.

Species	b_0 est.	SE	P-value	b_1 est.	SE	P-value	b_2 est.	SE	P-value
Sugar maple[a]	1.012	0.53	0.06	1.975	0.10	0.0001	–0.010	0.004	0.020
Yellow birch[a]	1.002	0.54	0.07	2.384	0.10	0.0001	–0.027	0.004	0.0001
Beech[a]	0.755	0.53	0.16	1.683	0.10	0.0001	–0.012	0.004	0.002
White ash[b]	1.131	0.51	0.03	1.847	0.04	0.0001			

NOTE: Models of the form: [a] quadratic (height $= b_0 + b_1 \times$ time $+ b_2 \times$ time^2) and [b] linear (height $= b_0 + b_1 \times$ time).

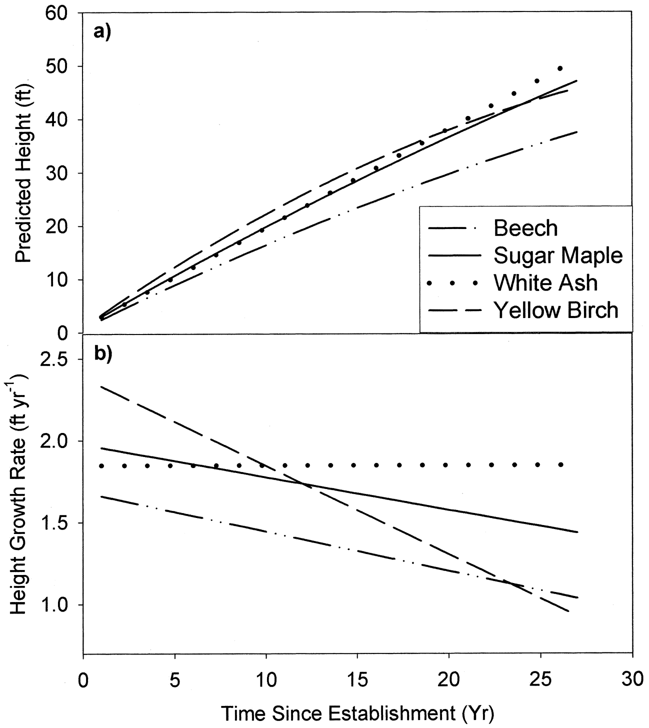

Figure 1. Predicted total height (a) and height growth rates (b) for main canopy trees of four northern hardwood species that became established following shelterwood cutting and understory herbicide treatment.

through a 25- to 30-year period in New York stands regenerated by either shelterwood method or clearcutting (Ray et al. 1999, Nyland et al. 2000). The assessments reported here suggest a consistent pattern of height development across stands and within species as well, at least among dominant stems (Figure 1a). For similar sites given understory beech control, we predict that yellow birch will be the tallest of the four species for the first 10 to 15 years following stand establishment. Sugar maple and white ash will be somewhat smaller, having comparable heights during that same period. Then, between ages 15 and 25, sugar maple, white ash, and yellow birch will not differ much in height. Beyond age 25, white ash will become notably taller, and beech consistently shorter, than these other species

Similar patterns of height development through 44–48 years were reported following group selection cutting in New Hampshire (McClure et al. 2000). Those openings had abundant advance regeneration of beech and sugar maple, but little yellow birch. Yellow birch grew the most rapidly through 15 years after cutting, and exceeded the height of beech through most of the four to five decades of development evaluated. As with our case, vertical development of both yellow birch and sugar maple slowed through time, and those two species had similar heights after 44–48 years. Beech also initially grew the slowest of all species, but at a fairly constant rate in the New Hampshire plots. As a result, its average height at 30 years matched that of yellow birch and sugar maple. Unlike the trees in our site-prepared even-aged communities, some of the advanced beech also grew into dominant crown canopy positions.

Our results indicate that by age 19, sugar maple, yellow birch, and white ash should be about 30–35 ft tall, and beech about 25–30 ft. These heights are shorter than the tallest trees on permanent plots in even-aged stands regenerated by clearcutting in central New York, where the trees averaged 40–51 ft tall at stand ages 17–20 (Wang and Nyland 1996). The clearcut stands include up to 10 species, with sugar maple, white ash, and black cherry as principal components of the upper canopy. The greater heights in central New York likely reflect the longer growing season, finer-textured soils, greater abundance of black and pin cherry (*Prunus pennsylvanica* L. f.), and the fact that sugar maple and beech occurred as advance regeneration prior to the reproduction method cutting.

Shade-tolerant species such as sugar maple and beech commonly become established as advance regeneration. For beech, the understory may have small trees of root sucker origin that develop rapidly following release by overstory cutting. The relative abundance of tall advance regeneration for these two species may profoundly influence the composition of a new cohort (Marquis et al. 1984, Leak 1988) and also determine whether a component of shade-tolerant species will develop into upper canopy positions in a new even-aged stand (Wang and Nyland 1993).

The importance of advance regeneration to the success of sugar maple and beech is illustrated by comparing our study to those in stands with abundant advance regeneration. Twenty years after clearcutting in central New York northern hardwood stands, sugar maple and beech stems accounted for 16% of the trees in a dominant crown position, and 60% of those classified as codominants (Heitzman and Nyland 1994). Likewise, 25 years after clearcutting in New Hampshire, 43% of the surviving beech and 58% of surviving sugar maple occupied dominant or codominant crown positions (Marquis 1967). By contrast, our Adirondack sites lacking advance regeneration had only about 3% of sugar maple survivors in dominant positions in the 24-year-old stand, and 26% were codominants. In the 29-year-old stand, only 1% of the sugar maples were classified as dominants, but over 15% were codominants. Altogether, sugar maple and beech accounted for only 11% of all upper-canopy trees in the 24-year-old stand, and 18% at 29 years. No sampled beech occupied a dominant crown position in our 24- or 29-year-old stands, due largely to the slow height growth of that species.

Our findings agree with those of Bicknell (1982) for New Hampshire northern hardwoods, both in terms of measured total heights (range 6–11 ft at age 6), and the relative early heights of these species (yellow birch > sugar maple = white ash > beech) up to about age 15. Taking account of the status of advance regeneration in that and other studies, we also see considerable consistency between our conclusions and the findings reported by Marquis (1967), Hill (1987), and McClure et al. (2000). This degree of agreement suggests a widespread pattern of consistent early height development for these species. Based on this evidence, we conclude that beech will not likely dominate the upper canopy of a new cohort after an even-aged regeneration method that includes a herbicide treatment to eliminate advance seedlings and root suckers of that species. Due to its sustained height growth, white ash will occupy the uppermost canopy positions by age 25, with the best-growing yellow birch and sugar maple mostly becoming codominants.

Our data also suggest that early differentiation by diameter may not be as informative as differences in height growth when assessing the competitive status of these four species. A correlation between growth rates and shade tolerance has been demonstrated for a number of northern hardwood species (Gilbert 1965, Yanai et al. 1998). We, too, found evidence to support this relationship. Specifically, shade-tolerant beech consistently had the smallest diameters at a given age, with those of sugar maple intermediate, and yellow birch and white ash the largest. Yet for the main canopy trees sampled in this study, species differentiation by height growth appeared less closely tied to shade tolerance. By age 25, beech had the shortest heights and white ash the tallest, but the heights of sugar maple and yellow birch did not differ significantly in any of the stands.

Our findings indicate that the base of the live crown on white ash had not risen above one log (16 ft) until age 20. For sugar maple, yellow birch, and beech it had not reached 16 ft until age 24. Consistent with these findings, Wang and Nyland (1996) reported an average clear length of 7–12 ft among their tallest trees at 10–13 years following clearcutting of northern hardwood stands in central New York, and 9–22 ft at 17–20 years. Their sample trees included more than just dominants and codominants and reflect the variation in tree heights and distances to the base of the live crown across the full range of crown classes in more species-diverse communities.

Our data indicate that upper-canopy trees should have sufficient vigor to allow a delay of early tending through at least three decades. At that age, the live-crown ratios of upper canopy trees in our Adirondack stands were ~40%. Similarly, crown lengths remained high in central New York clearcuts through at least the first 20 years (Wang and Nyland 1996).

Management Implications

We observed important differences in height growth rates among four northern hardwood species through 29 years following shelterwood method seed cutting preceded by site preparation to control the dense beech understory. Forest managers can use the prediction equations (Figure 1, Table 2) to forecast how stands given similar reproduction method treatments will likely develop. The findings indicate that if beech, sugar maple, yellow birch, and white ash become established at a common time, main canopy stems of the latter three species will likely outgrow most beech stems by the end of one decade, and be taller than even the largest beech by 20 years of age. This corroborates past observations that appropriate site preparation will minimize the numbers of beech that reach upper canopy positions in young even-aged northern hardwood stands.

Our data also give an indication of the trends in timber-quality production within young, even-aged stands and when to schedule a first tending operation. Based on our observations, the base of the crown for white ash should reach at least 26 ft by the end of three decades, and be at 20 ft for the other species. We propose delaying a first entry until that time. Earlier stand tending will likely keep the lower branches alive, delaying the development of clear length on the crop trees, and increasing the chances of heavy low forking. Tree vigor should remain adequate through at least 30 years to insure a good growth response on the crop trees after release. Thus, postponing the first tending for three decades will insure at least one clear log on upper-canopy trees, but not result in a loss of their vigor due to inter-tree competition.

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