Contrasting Release Approaches for a Mixed Paper Birch (*Betula papyrifera*)–Quaking Aspen (*Populus tremuloides*) Stand

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ABSTRACT

Early release from competitors can be used to influence the species composition, quality, and rate of development of young stands. Release strategies can vary in intensity, ranging from complete removal of competitors and infrequent future entries (early, heavy, infrequent [EHI]) to lighter entries that are repeated more frequently (early, light, often [ELO]). It is unclear, however, which strategy is more successful for producing high-quality birch sawtimber (*Betula papyrifera* Marsh.) in mixed stands with aspen (*Populus tremuloides* Michx.). We evaluated the effects of various release intensities on the growth and mortality of a 16–18-ft-tall natural aspen–paper birch stand in Minnesota following density reductions from 1,500–3,000 trees ac^{-1} (trees per acre [TPA]) to 750 (ELO750), 500 (EHI500), and 250 (EHI250) TPA. After 6 years, paper birch was overtopped by aspen and contributed only 14% of basal area in control plots, but it occupied all diameter classes and contributed 77–87% of basal area in release plots. The basal area and volume of all paper birch and of only paper birch crop trees (100 largest TPA) were highest in lightly released ELO750 and lowest in control plots. Growth of mean quadratic diameter, basal area, and volume of paper birch was 2–3 times higher in release plots but independent of release intensity. Early release is necessary to maintain paper birch dominance, but there is no short-term advantage among treatment intensities. Long-term growth simulations using the Forest Vegetation Simulator suggest that merchantable timber production was unaffected by release strategy but that the EHI250 strategy produced the most birch sawtimber (40 times as much as in ELO750).

Keywords: *Betula papyrifera*, crop tree, Forest Vegetation Simulator, growth, release

Paper birch (*Betula papyrifera* Marsh.) is an important early seral species in the Lake States that commonly regenerates in mixed stands with quaking aspen (*Populus tremuloides* Michx.), big-toothed aspen (*Populus grandidentata* Michx.), and red maple (*Acer rubrum* L.) (Perala and Alm 1990). If left unmanaged, suckers of fast-growing aspen and red maple sprouts overtop paper birch during the sapling stage, reducing birch presence in the stand (Eyre and Zillgitt 1953, Marquis 1967, LaBonte and Nash 1978, LaBonte and Leso 1990). Since most mixed aspen–birch–conifer stands in the Lake States were grown for pulpwood (Ohmann et al. 1978), the loss of paper birch has been of little concern. Recently, however, interest in birch has increased for clean, straight, high-quality stems for veneer, lumber, flooring, and furniture products (Peterson et al. 1997), as well as for specialty products such as musical instruments, rustic furniture, and birch bark canoes and baskets (Zasada 2002). In this context, early release treatments may have to be considered to maintain the birch component in mixed-species stands and to enhance the production of high-quality birch timber of sawlog size required for high-end products.

When mixed with aspen and red maple, paper birch management guidelines in the Northeastern United States call for a complete removal of these competitors as early as possible to leave a uniformly spaced stand of birch (Marquis et al. 1969, Safford 1983). This release is usually implemented through a single entry (Safford 1983), whereby subsequent thinning entries are indefinitely delayed or at least for several decades (early, heavy, infrequent [EHI]). Complete weeding "should provide the largest quantities of high-quality paper birch" (Safford 1983, p.19), but removing all aspen and red maples may result in incomplete use of growing space. Incomplete use of growing space often results in reduction of total stand biomass production (Safford 1983, Dwyer and Lowell 1988, Peterson et al. 1997). It also can lead to shorter clear boles because of delayed self-pruning and increased branch size and stem taper (Marquis et al. 1984, Heitzman and Nyland 1991, Niemistö 1995, Simard et al. 2004), thus precluding development of high-quality sawtimber. Following the more common approach of gradual tree density reduction through moderate release and repeated thinning entries, early, light, often (ELO), may provide sufficient growing space to balance competition-related birch mortality with maximum growth potential, complete utilization of site resources, and production of high-quality sawlogs (Godman and Marquis 1969, Safford 1983, Leak and Solomon 1997, Graham 1998, Simard et al. 2004).

Decisions about timing and intensity of early release in young stands need to balance a complex set of issues, including stand dynamics, desired diameter growth rates of individual trees, quality requirements of clear boles and small knot sizes, and stand production goals (Godman and Marquis 1969, Peterson et al. 1997). However, no specific information exists documenting the response of young, naturally regenerated aspen-birch stands to early release treatments of different intensities in the Lake States. Our study is

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aimed at providing this information. Specifically, we were interested in quantifying how the growth dynamics in a mixed sapling aspen-birch stand are influenced by release aimed at favoring birch and whether release can help birch remain the dominant species. Second, we wanted to gain insight into stand development by comparing the response of trees in different size classes and by contrasting the tree and stand response of all birches and specifically of birch crop trees to release. Finally, to put the short-term responses in perspective, we used the Forest Vegetation Simulator (Miner et al. 1988) to explore whether or not different early release intensities, as well as a 10-year delay in early release, would result in differences in merchantable birch timber and sawtimber production over a rotation.

Study Area

The study was conducted at the Cloquet Forestry Center in north-central Minnesota (46°43′N, 92°29′W), which has a continental climate with long, cold winters, warm summers, and moderate precipitation distributed uniformly throughout the year (Alban et al. 1991). Mean temperatures are 61–66°F during the growing season and 39°F annually, and annual precipitation is 30 in. (Alban et al. 1991). The study area is on gently rolling outwash plain (Wright et al. 1970) with acidic outwash drift high in gravels (Alban et al. 1991).

In the summer of 1979, a two-cut uniform shelterwood was initiated as part of a research project in a 60-year-old mixed paper birch–aspen stand by reserving all paper birches (Perala and Alm 1989). Total stand basal area of the mature stand was 87 ft^2 ac^{-1}, and site index for paper birch (Lundgren and Dolid 1970) was 54 ft at age 50. In the fall of 1982, 95% of the germination plots were stocked with birch, and total seedling density was 222 per milacre, of which 14 per milacre were 2-year-olds with 63% stocking, and the rest were 1-year-olds (Perala and Alm 1989). In the fall of 1985, total paper birch seedling density had declined to 22 per milacre with 68% total stocking, and the oldest birch seedlings averaged 34 in. tall. In the winter of 1985/1986, the shelterwood overstory was removed.

Methods

Experimental Design, Treatments, and Measurements

In the summer of 1996 (age, 15 years), four levels of release were applied to cover a wide gradient of release intensity incorporating both an EHI approach and an ELO approach, as well as a no-release control. The most-intensive treatments (250 trees per acre [TPA] [EHI250] and 500 TPA [EHI500]) followed the intent of eastern paper birch guidelines and eliminated most, if not all, aspen and red maple, leaving mostly paper birch. Although no specific target numbers existed in 1996 on which to base the EHI250 and EHI500 treatments, a recently published study from British Columbia suggests that thinning 9–13-year old stands (2 in. quadratic mean diameter [QMD], 25 ft top height) to approximately 400 TPA may be the most successful for balancing competition-related mortality with maximum growth potential and complete utilization of site resources; thinning to approximately 160 TPA resulted in the largest and most sustained diameter growth response but incomplete use of growing space (Simard et al. 2004). The least-intensive treatment [750 TPA (ELO750)] reflects recommended conditions at ages of approximately 20 to 25 years (approximately 5 in. dbh) after releasing 300–400 crop trees ac^{-1} (Safford 1983). The ELO750 treatment was selected with the assumption that multiple future thinnings would be implemented to stimulate and concentrate growth on the most desirable trees.

Release intensities were randomly assigned to 12 treatment plots, each treatment being replicated three times. Despite efforts to select homogenous stand conditions, one treatment plot in the ELO750 and one control plot were gross outliers and omitted from all analyses. The omitted treatment plot in the ELO750 treatment contained few, very large trees that resulted in a basal area that was twice as high as both other replicates and even higher than the control plots. The paper birch contribution to the omitted control plot was less than 7% by density (compared with 27 and 43% in the other control plots). Treatment plots were 164 × 164 ft (0.62 ac), in which 49.2-ft-radius measurement plots were centered.

Trees were selected and marked in the spring, and treatments were applied in June and July of 1996 to minimize sprouting. Preference as leave trees was given to paper birch, but red maple and aspen were also retained where no birch individuals occurred to meet the spacing requirements. Selection criteria for paper birch leave trees were as follows: (1) upper crown classes, (2) vigorous and healthy stem, (3) good bole quality, and (4) uniform spacing relative to other leave trees. Birch stump sprouts were thinned to one or two sprouts that were the most vigorous and straight and that started low on the stump. Trees were cut near the bole collar using circular brush saws. All leave trees inside the measurement plots were number tagged.

Measurements and Statistical Analysis

Postthinning measurements on leave trees were conducted in the fall of 1996 and after six growing seasons in the spring of 2003 and included dbh for all trees, as well as height and height to the first branch, on a subset of 180 paper birch trees (15 per plot). In each plot, this subset was composed of the same five paper birch trees that were randomly chosen from within each of three size classes from a partition of the 1996 diameter distribution. For volume calculation, heights for the remaining trees in all treatments were estimated using third-order polynomials of measured heights as a function of dbh ($R^2 = 0.84$ and 0.72 for 1996 and 2003, respectively) developed from this subset of trees. The volume equation used was from Gevorkiantz and Olsen (1955) as modified by Ek (1985). Basal area and volume were determined by summing basal area and volume values for all trees in a plot. Plot means of tree density, QMD, basal area (ft^2 ac^{-1}), and volume (ft^3 ac^{-1}), as well as tree height, top height (the 60 trees in the upper canopy class, corresponding to the average height of the 40 largest birch stems ac^{-1}), and height to the first live branch for paper birch, were computed for all trees, birch trees only, and paper birch crop trees (the 100 birch stems ac^{-1} with the largest initial diameter) for years 1996 and 2003. Mortality and growth of height and diameter were calculated as the difference between live tree densities, heights, and diameters measured in 2003 and 1996 and averaged for each plot. To investigate diameter growth for differently sized trees, paper birch trees were grouped into three 1-in. diameter classes on the basis of initial diameters (i.e., 0–1, 1.01–2, and 2.01–3 in.). Basal area and volume growth were calculated for each tree alive in 2003 and summed to the plot level.

To test for effects of release intensity on 6-year overall stand and paper birch growth (i.e., difference between 2003 and 1996 values of response variables), we used analysis of covariance with initial post-release means as covariates. In all analyses, multiple comparisons among treatments were made using Tukey-Kramer multiple comparisons tests. To avoid the necessity for transforming response variables in case of nonconstant variances (i.e., with a log transformation), the analysis of covariance was weighted with the inverse of the variance in each treatment class, which corrects nonconstant variance (Myers 1990, p. 277f;

Table 1. Pretreatment (1996) means ± standard errors of stand attributes (tree/birch density, quadratic mean diameter [QMD], mean height, top height [tallest 40 trees per acre (TPA)], height to the first live branch, live crown ratio [LCR], total basal area [BA], and total volume [Vol] of all trees, the paper birch component, and birch crop trees [100 largest TPA]) by release treatment.

Stand attributes	Control	ELO750	EHI500	EHI250	*P* value
Overall stand conditions (all trees)					
Tree density (stems ac^{-1})	2141 ± 553^{a}	779 ± 45^{a}	550 ± 49^{b}	248 ± 5^{c}	<0.001
QMD (in.)	1.2 ± 0.1^{a}	$1.1 \pm 0.2^{a,b}$	0.8 ± 0.1^{b}	$1.1 \pm 0.3^{a,b}$	0.010
BA (ft^2 ac^{-1})	18.6 ± 6.5	4.9 ± 1.4	1.8 ± 0.4	1.8 ± 1.0	0.080
Volume (ft^3 ac^{-1})	184.5 ± 62.0	41.9 ± 13.6	13.7 ± 3.4	16.4 ± 10.9	0.090
Paper birch conditions					
Birch density (stems ac^{-1})	707 ± 37^{a}	$707 \pm 83^{a,b}$	488 ± 24^{b}	195 ± 34^{c}	<0.001
Height (ft)	16.7 ± 0.2	18.4 ± 0.8	15.6 ± 0.5	16.1 ± 3.7	0.102
Height to live branch (ft)	5.2 ± 1.0	5.6 ± 1.0	4.2 ± 0.8	4.4 ± 0.8	0.631
LCR (%)	67.9 ± 1.7	68.3 ± 1.7	71.7 ± 1.4	72.4 ± 1.4	0.194
QMD (in.)	0.8 ± 0.2	1.0 ± 0.2	0.8 ± 0.2	1.0 ± 0.2	0.582
BA (ft^2 ac^{-1})	$2.3 \pm 0.6^{a,b}$	8.5 ± 0.6^{b}	1.6 ± 0.4^{a}	1.2 ± 0.4^{a}	0.027
Volume (ft^3 ac^{-1})	$18.3 \pm 5.6^{a,b}$	34.6 ± 5.6^{b}	11.9 ± 4.4^{a}	10.6 ± 4.4^{a}	0.034
Paper birch crop tree conditions					
Top height (ft)	21.6 ± 0.8	23.1 ± 1.0	20.0 ± 0.6	21.3 ± 4.9	0.150
Height to live branch (ft)	5.8 ± 1.3	5.5 ± 1.3	4.6 ± 1.0	5.3 ± 1.0	0.905
LCR (%)	73.3 ± 0.6	76.1 ± 3.3	76.6 ± 1.2	75.9 ± 2.3	0.198
QMD (in.)	1.4 ± 0.3	1.7 ± 0.3	1.3 ± 0.2	1.3 ± 0.2	0.633
BA (ft^2 ac^{-1})	1.0 ± 0.4	1.6 ± 0.4	1.0 ± 0.3	1.0 ± 0.3	0.645
Volume (ft^3 ac^{-1})	9.7 ± 4.3	15.4 ± 4.3	8.1 ± 3.4	9.7 ± 3.4	0.624

[a,b,c] The same letters indicate that pretreatment means are not statistically significantly different ($\alpha = 0.05$).
EHI, early, heavy, and infrequent; ELO, early, light, and often.

Ramsey and Schafer 1997, p. 314). All statistical analyses were performed in SAS (release 9.1; SAS Institute 2002). Statistical significance was assessed at the $\alpha = 0.05$ level; results were considered marginally significant if *P* values were less than 0.10.

Modeling Procedure

To put the differences in early release intensity into a broad perspective, we used an individual tree distance-independent model (the Lake States TWIGS variant of the Forest Vegetation Simulator (FVS-LS) (Miner et al. 1988) to project long-term growth, yield, and mortality responses. Two different questions were explored in the modeling work. First, does the EHI250 treatment result in the highest projected merchantable birch timber and sawtimber production in the absence of additional thinning entries beyond the release of 1996? Second, does a 10-year delay in initial release result in projected reductions in merchantable birch timber and sawtimber production over a rotation compared with early release? The ingrowth feature for natural regeneration following release in FVS-LS was turned off for the simulations. A rotation of 80 years was chosen to evaluate differences in birch timber and sawtimber production. Merchantable timber is defined as trees with a minimum dbh of 6 in. with at least one 8-ft bolt with a top diameter inside bark of at least 4 in. Sawtimber must have an 11-in. dbh and have at least one 8-ft bolt with a top diameter inside bark of at least 9.6 in. (Miner et al. 1988). Although we recognize the uncertainties inherent in using a simulation model to predict future stand conditions, we opted to use statistical tests (analysis of variance, weighted, if needed) with the Tukey-Kramer multiple comparisons test procedure) to test and report *P* values for differences in long-term QMD and production of merchantable birch timber and sawtimber among different levels of early release intensities.

Results

Initial Posttreatment Conditions

As expected, initial tree densities and paper birch densities were significantly different among all treatments (Table 1). Paper birch densities ranged from 665 to 744 TPA in the controls, 624 to 790 TPA in ELO750, 446 to 533 TPA in EHI500, and 149 to 258 TPA in EHI250. Control plots had the highest proportion of nonbirch trees, and paper birch occupied the smaller tree size classes (Figure 1). In release plots, the relative position of the tree species changed such that paper birch dominated all diameter classes. As a result of thinning large aspen, initial values of average tree sizes (QMD) were smaller and residual basal areas and volumes were lower (74–90% for basal area and 77–95% for volume) in release plots than controls, but not significantly different among release intensities. Initial values of paper birch mean height, height to the lowest live branch, live crown ratios, and QMD were not significantly different among treatments, but paper birch basal areas and volumes were significantly higher in ELO750 than in EHI500 and EHI250 plots. None of the initial measures of paper birch crop trees differed significantly among treatments.

Short-Term Growth Responses

Overall Stand Responses

Overall stand dynamics were strongly influenced by the preferential removal of nonbirches and by the density reduction itself. Most of the 6-year tree mortality (87.6%) occurred in control plots, where mortality was significantly higher than in release plots ($P = 0.039$), and aspen density decreased by 28 ± 5%. Mortality in EHI250 was restricted to aspen and red maple. There were statistically significant positive release effects on overall 6-year QMD growth ($P = 0.002$) and basal area growth ($P = 0.006$), and marginally significant effects on volume growth ($P = 0.06$). Basal area growth was significantly higher in ELO750 than EHI500 ($P = 0.036$) and EHI250 ($P = 0.004$) but not the controls ($P = 0.31$). Volume growth was higher in ELO750 than in EHI500 and EHI250, but the effect was only marginally significant ($P = 0.08$ and $P = 0.052$, respectively); volume growth in ELO750 was not different from that of the controls ($P = 0.55$).

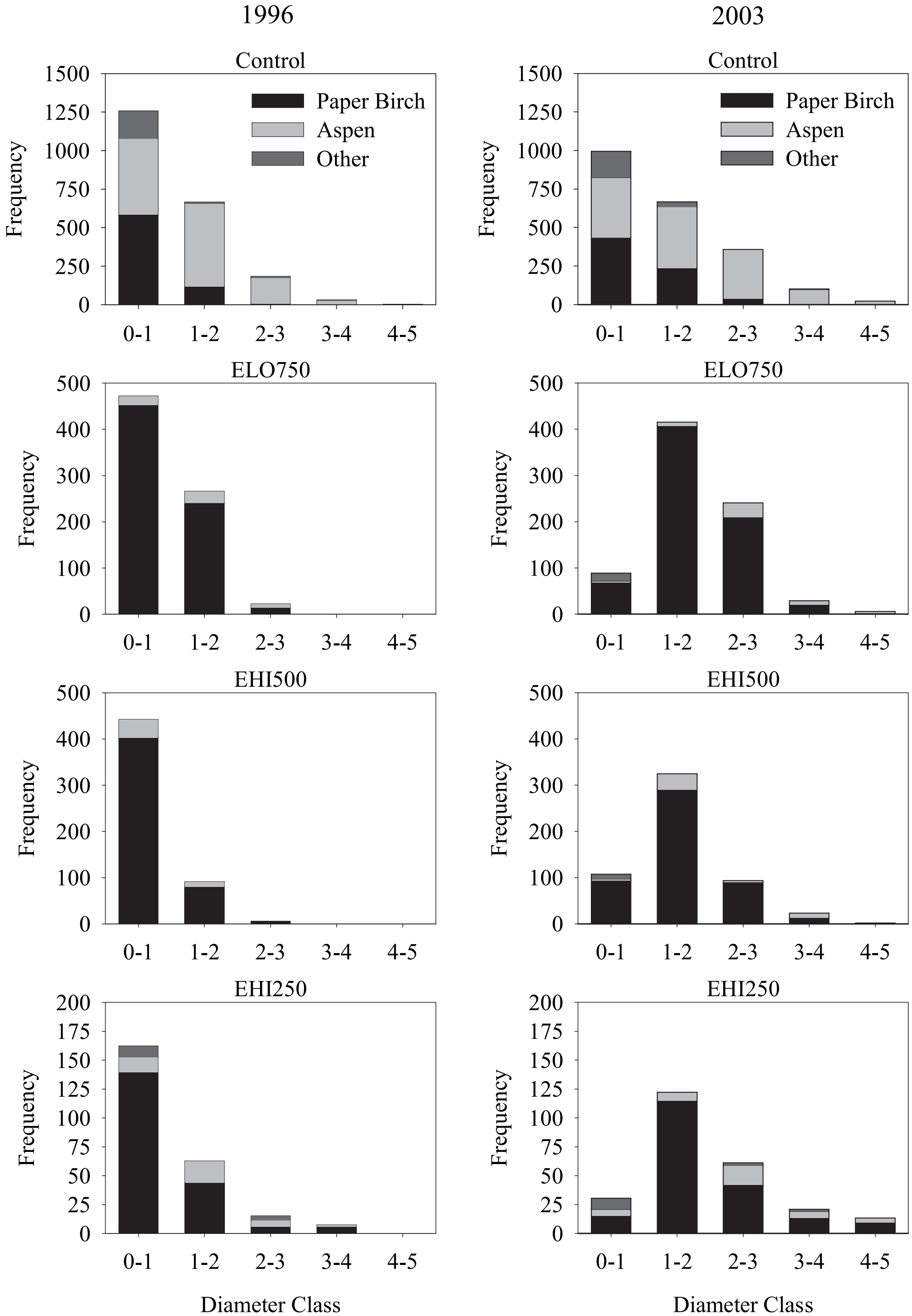

Figure 1. Frequency distributions across treatment replications of paper birch, aspen, and other species (mostly red maple) by diameter class in 1996 (left) and 2003 (right). EHI, early, heavy, and infrequent; ELO, early, light, and often.

Paper Birch Responses

Mortality patterns over 6 years were significantly affected by release intensity ($P = 0.013$), with significantly higher birch mortality in control (56% of all birch mortality) and ELO750 plots than in EHI500 and EHI250 plots. Birch mortality in ELO750 was approximately twice as much as in EHI500 and approximately half that of the control plots. No birch mortality was observed in the EHI250 plots through the entire measurement period. Mortality patterns did not randomly affect trees, as all paper birch that died were <1.2 in. in dbh. There were no statistically significant release

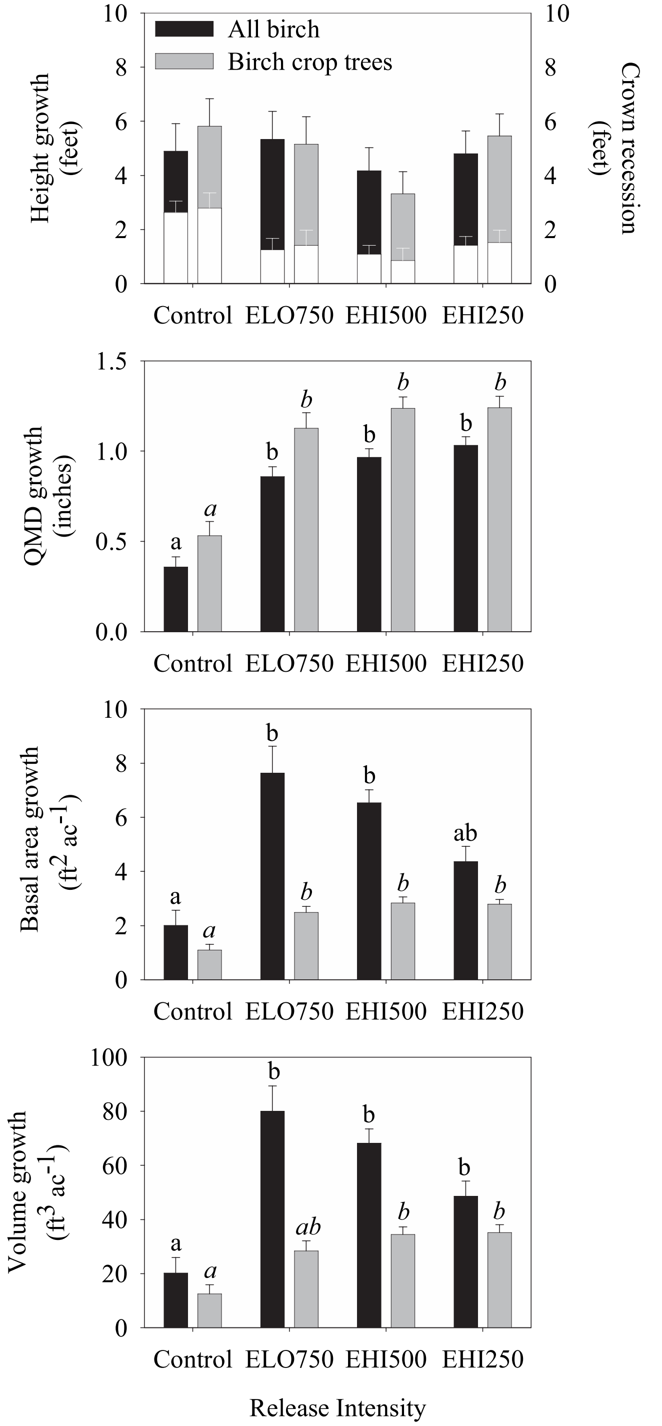

Figure 2. Effects of different release intensities on 6-year crown recession and growth of height (all birch), top height (crop trees), quadratic mean diameter (QMD), basal area (ft^2 ac^{-1}), and volume (ft^3 ac^{-1}) between 1996 and 2003. Responses of all birch trees are in black columns, responses of birch crop trees in gray columns, and height to lower live crown in white columns. Columns with the same letters for the entire stand (roman letters) and the birch component only (italic letters) had no statistically significant difference (α = 0.05). EHI, early, heavy, and infrequent; ELO, early, light, and often.

effects on 6-year height growth ($P = 0.99$) and change in height to crown base ($P = 0.13$). In contrast, 6-year growth of QMD, basal area, and volume responded significantly to release (all $P < 0.001$)

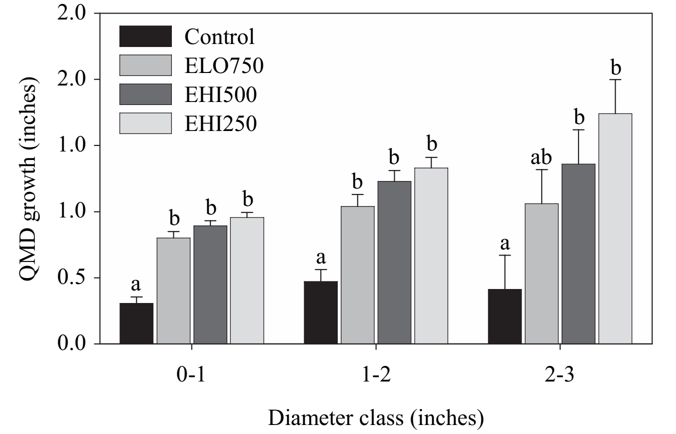

Figure 3. Effects of different release intensities on 6-year growth of quadratic mean diameter (QMD) of paper birch in different initial diameter classes. Columns with the same letters in each diameter class were not statistically significantly different (α = 0.05). EHI, early, heavy, and infrequent; ELO, early, light, and often.

but not significantly differently to release intensities (all $P > 0.10$; Figure 2). The greatest growth response of QMD occurred in EHI250, followed by EHI500 and ELO750, and was observed regardless of initial diameter class (Figure 3). Growth responses of basal area and volume were greater in ELO750, followed by EHI500 and EHI250. On average, growth of QMD, basal area, and volume was approximately 2–4 times as much as is released in control plots.

Paper Birch Crop Trees

Similar to growth patterns observed for all paper birch, there was no statistically significant release effect on 6-year height growth ($P = 0.79$) and crown lift ($P = 0.17$), but growth of QMD ($P < 0.001$), basal area ($P = 0.005$), and volume ($P = 0.013$) responded significantly to release but not significantly differently to release intensities (all $P > 0.5$; Figure 2). On average, growth of QMD, basal area, and volume of birch tree crop trees in release plots was approximately 2–3 times that of control plots.

Long-Term Growth Projections

Projected long-term stand and birch densities were significantly lower in EHI250 than in all other treatments at rotation age of 80 years (Table 2). The proportion of birch, based on stand density, was significantly lower in controls than release plots. The projected QMD was significantly higher in EHI250 than in all other treatments. Intensive early release enhanced merchantable timber production compared with control and ELO750 treatments (Figure 4), but this increase was only marginally significant ($P = 0.10$ and $P = 0.056$, respectively). In contrast, the production of merchantable birch timber was approximately 6 times as much as is released in control plots ($P = 0.006$). Paper birch contributed only 15% to the total merchantable timber production in control plots. Neither total merchantable timber production (all $P > 0.3$) nor merchantable birch production (all $P > 0.9$) was significantly different among release treatments, however. Overall sawtimber production differed among treatments ($P < 0.001$); it was highest in EHI250 and control plots because of remaining aspen and lowest in ELO750 and EHI500 plots. Similarly, production of birch sawtimber differed among treatments ($P = 0.024$) and ranged from zero in control

Table 2. Means ± standard errors of stand projections at age 80 years without additional stand entries beyond release in 1996 using the Lake States version of the Forest Vegetation Simulator.

Response	Control	ELO750	ELO500	ELO250	*P* value
Stand density (stems ac^{-1})	361 ± 14[a]	407 ± 25[a]	361 ± 7[a]	188 ± 16[b]	<0.001
Birch density (stems ac^{-1})	250 ± 34[a,b]	397 ± 31[a]	343 ± 4[a]	164 ± 29[b]	0.002
Birch proportion (%)	69 ± 7[a]	98 ± 1[b]	95 ± 1[b]	86 ± 8[a,b]	0.049
QMD (in.)	7.9 ± 0.1[a]	7.8 ± 0.3[a]	8.3 ± 0.1[a]	10.9 ± 0.5[b]	0.007

[a,b] The same letters indicate that treatment means are not statistically significantly different ($\alpha = 0.05$).
ELO, early, light, and often; QMD, quadratic mean diameter.

plots to approximately 304 ft^3 ac^{-1} in EHI250 plots, which was 40 and 10 times as much as in ELO750 and EHI500 plots, respectively. Paper birch contributed 0, 7, 15, and 39% to the proportion of the total sawtimber production in control, ELO750, EHI500, and EHI250 plots, respectively.

Even a single release entry in the controls in either 1996 or 2006 would have substantially enhanced projected QMD, merchantable birch timber, and birch sawtimber, regardless of release intensity (Table 3). Furthermore, applying ELO750, EHI500, and EHI250 treatments in controls in 1996 instead of 2006 would have further resulted in at least a doubling of sawtimber and birch sawtimber production in all treatments, with the largest relative gains in ELO750 and the highest absolute values in EHI250 (Table 3).

Discussion

The purpose of this study was to investigate effects of different release intensities on composition, quality, and rate of development of a mixed paper birch–aspen stand. Early release has been promoted to maintain or increase the proportion of desired species in dominant or codominant positions through stand development and to enhance their vigor and competitiveness (Miller 2000). The simulation results of this study suggest that the main long-term impact of even a single intensive early release treatment in this mixed aspen-birch stand is continued birch dominance throughout stand development, as well as the increased potential for birch sawtimber production. It is too early to determine whether a single-intensive release treatment will affect the quality of the final stand.

The benefits of early release for maintaining paper birch as a dominant stand component are evident from the substantially altered structure and composition of the release plots in this study. The early stand stages are very dynamic, and delaying release even a few more years would have further relegated paper birch to smaller size classes, with a loss of codominance to aspen and increasing birch mortality, as made evident by the current conditions in the control plots. In contrast, selective release to favor paper birch ensured that it is represented across the whole diameter distribution, is present in the dominant and codominant crown classes, and comprises the majority of the basal area. Paper birch responded positively to the reduced competition by increasing diameter, basal area, and volume growth, which is consistent with other studies (e.g., Marquis 1969, Voorhis 1990, Graham 1998, Simard et al. 2004). It is expected that the open growing conditions created by low stocking will likely persist for some time and that the higher resource levels available to individual trees will result in prolonged enhanced growth in the release treatments (Della-Bianca 1975, Erdmann et al. 1975, Smith and Lamson 1983, Miller 2000, Simard et al. 2004, Schuler 2006). Long-term studies of similar treatments and our modeling results lead us to further expect that most paper birch will eventually succumb to mortality in untreated plots, whereas it will continue to be a major component of release plots (LaBonte and Nash 1978). This can already be seen in our short-term results, where no birch mortality was observed in the most-intensive release treatments and where a mortality rate of 5.5% in our control plots was identical to that observed by Simard et al. (2004) and appeared to be primarily due to competition from overtopping aspen. Our modeling results confirm this as well. For example, the FVS-based average crown cover estimates in 2003 are 14% in the EHI250 and 34.5% in the ELO750 treatments. These levels are sufficiently low for future competition-related birch mortality to be minimal in release plots.

In hindsight, it appears that the selected release intensities either did not have enough time or did not cover a wide enough gradient to detect any differential response to the range of residual densities. All release treatments resulted in somewhat similar stand development, as even our lightest intensity release may have freed paper birch crowns sufficiently from competition to provide "open" growing conditions. Compared with management guidelines in the northeastern United States, even the ELO750 treatment was relatively intensive and resulted in low stocking levels. The crown cover estimates in ELO750 treatment indicate that canopies have still not closed and that all release intensities provided ample growing space. Incomplete use of growing space may further be deduced from the observed high live crown ratios of crop trees that ranged from 74 to 77% in release plots. All of these values are in excess of the recommended minimum of 40–50% for high-quality crop trees (Gilbert and Jensen 1958), indicating that crop trees may have experienced similar, and minimal, levels of competition at all release intensities in this study up to this point. Owing to low stocking and incomplete use of growing space in all release plots, six growing seasons may still be too early for different release intensities to have resulted in significant short-term basal area and volume growth differentiation of paper birch crop trees in this study (see also Voorhis 1990, Simard et al. 2004). However, birch is very responsive to open growing conditions, and future competition-induced growth reductions in birch crop trees may be expected in the less intense release treatments (Safford et al. 1990).

In the short term, clear stem development was slightly (up to 2 ft) greater for control than for released trees during the first 6-year growth period. This was most likely due to the additional crown growing space afforded to released trees, which tends to reduce natural pruning (Miller 2000). It is too early to evaluate long-term stem quality in this study, as these results are not yet conclusive, but this trend does lead to concerns that more aggressive release could adversely affect stem quality by delaying natural self-pruning of lower branches, increasing branch size and stem taper, and reducing clear bole length (Godman and Marquis 1969, Erdmann et al. 1975, Heitzman and Nyland 1991, Simard et al. 2004). The trend of slower crown lifting in release plots has been documented to persist in long-term studies (Conover and Ralston 1959, Niemistö

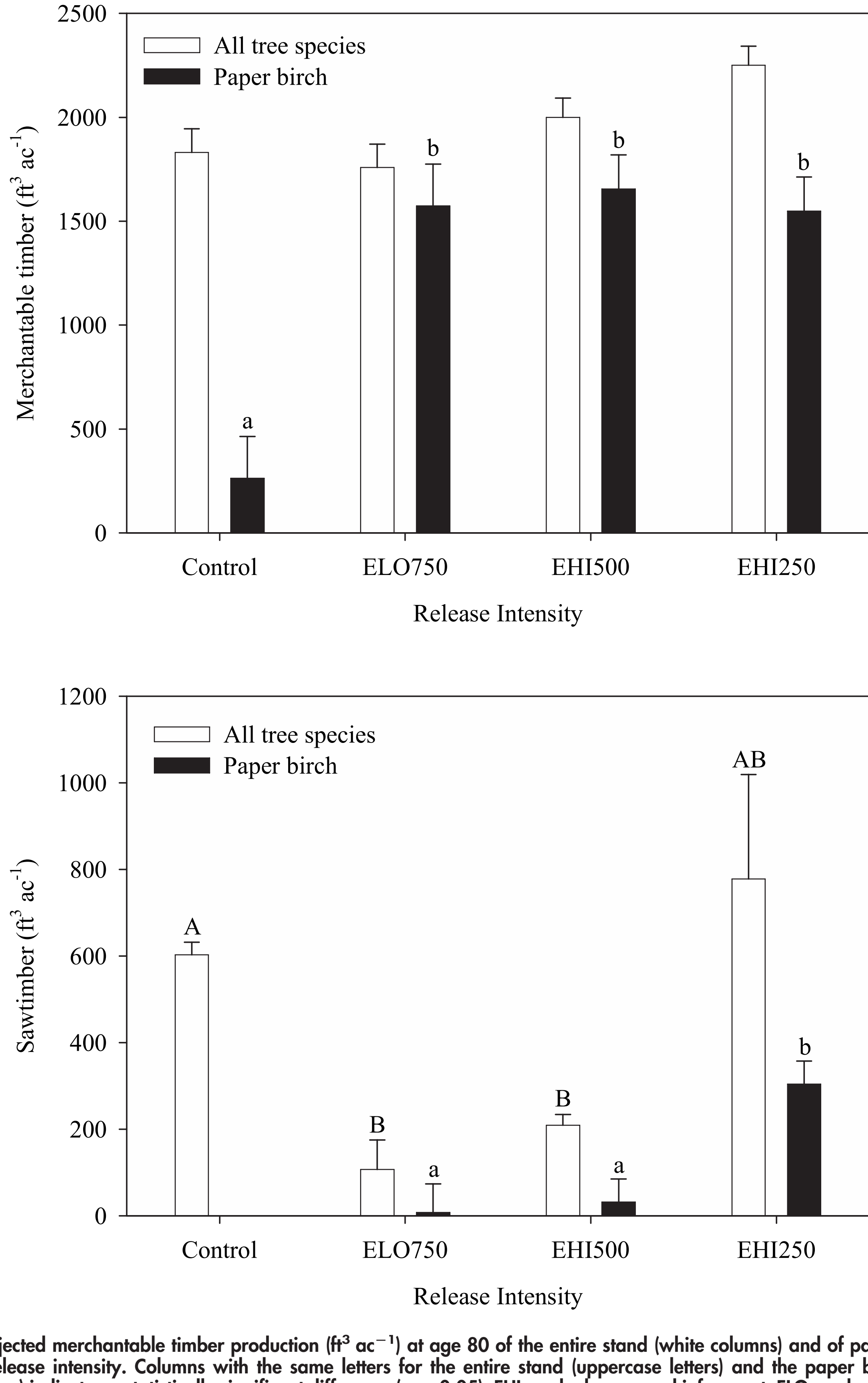

Figure 4. Projected merchantable timber production (ft^3 ac^{-1}) at age 80 of the entire stand (white columns) and of paper birch (black columns) by release intensity. Columns with the same letters for the entire stand (uppercase letters) and the paper birch component (lowercase letters) indicate no statistically significant difference (α = 0.05). EHI, early, heavy, and infrequent; ELO, early, light, and often.

1995), although this trend can be reversed after canopy closure, when released trees may show greater increases in clear stem length than controls (Miller 2000). Although we do not expect crown closure to aid clear stem length development in the more aggressive EHI treatments in the near future in this study, the possibility that sprouts of aspen and red maple may provide some shade to the birch

Table 3. Projected quadratic mean diameter (QMD), merchantable timber, merchantable birch timber, sawtimber, and birch sawtimber production at age 80 years for two control plots without any stand entries compared to a hypothetical first release in 1996 or 2006 with no followup thinning. Due to low number of replications ($n = 2$), no statistical analysis was attempted. Despite comparable levels of merchantable timber production among different treatments, QMD, merchantable birch timber, and birch sawtimber productions benefited greatly from early release. Earliest release resulted in greatest tree sizes and values.

	No stand entry	Release 1996			Release 2006		
		ELO750	EHI500	EHI250	ELO750	EHI500	EHI250
QMD (in.)	7.9 ± 0.1	10.9 ± 0.0	10.9 ± 0.4	11.7 ± 0.2	9.4 ± 0.2	10.2 ± 0.1	10.7 ± 0.1
Merchantable timber ($ft^3\ ac^{-1}$)	1831 ± 113	2350 ± 98	2290 ± 37	2442 ± 76	2264 ± 126	2027 ± 28	2100 ± 39
Merchantable birch timber ($ft^3\ ac^{-1}$)	263 ± 201	2059 ± 194	2100 ± 39	2442 ± 76	1777 ± 28	2027 ± 28	2100 ± 39
Sawtimber ($ft^3\ ac^{-1}$)	603 ± 29	352 ± 35	506 ± 112	775 ± 44	146 ± 24	152 ± 4	308 ± 38
Birch sawtimber ($ft^3\ ac^{-1}$)	0 ± 0	337 ± 50	506 ± 112	775 ± 44	42 ± 29	152 ± 4	308 ± 38

EHI, early, heavy, and infrequent; ELO,early, light, and often.

boles in the future cannot be excluded either. Nonetheless, for EHI treatments, Safford's (1983) suggestion to prune fast-growing birch in more open stand conditions may be advisable, at least for selected trees that show potential for sawlog or veneer-quality logs.

On the basis of experiences with other hardwoods with weak epinastic control (e.g., black cherry (*Prunus serotina* Ehrh.), Trimble 1973, Miller 2000, Schuler 2006), we had expected that the high release intensities would have resulted in reduced height growth, but no height growth reductions were observed in any treatment. This lack of response has been documented in other birch thinning studies as well (Marquis 1969, Graham 1998, Simard et al. 2004), except under very low densities (see Heitzman and Nyland 1991, Niemistö 1995, Simard et al. 2004), which suggests that our release intensities were not sufficient to trigger this response.

It is important to note, however, that we used only short-term study results and had to rely on FVS growth model projections in lieu of long-term growth data to project the future outcome of our initial treatments. As with all simulation models that have been developed for a large region, results for a particular study area have to be interpreted with caution. Nonetheless, our simulation projections resulted in similar yield estimates as has been reported for paper birch stands on similar sites in Ontario (Safford et al. 1990). Simulation results strongly confirm our hypothesis that the EHI250 treatment appears to be the superior release strategy for producing large birch trees and birch sawtimber if no further thinning entries take place (Table 2; Figure 4). However, no release strategy had clear advantages for the production of merchantable timber and merchantable birch timber. Compared with the common practice of not entering mixed aspen-birch stands at all throughout the rotation, applying the EHI500 and ELO750 treatments increased the projected production of paper birch merchantable timber, decreased overall projected production of sawtimber, and maintained similar overall projected merchantable timber production. Finally, delaying early initial release by even a decade appears to have long-term negative effects on birch sawtimber and merchantable birch timber production.

Conclusions

Combining analyses of measured short-term effects of early release with long-term growth simulations provided us with an opportunity to put our management strategies in a long-term perspective. Results clearly indicate that ELO and EHI treatments sacrificed short-term stand volume production. However, for most birch management scenarios, this is less important than ensuring that paper birch remains the dominant species and will not be threatened by fast-growing species in the near future. Although none of the tested release strategies had clear advantages over others in the short term, early release led to significantly improved birch growth and reduced birch mortality compared with controls. For mixed stands in which only a single treatment will be applied throughout the rotation, long-term projection results indicate that the EHI approach appears to provide adequate merchantable timber and may allow for increased paper birch sawtimber production, although perhaps at some risk of reduced stem quality. Long-term monitoring of growth and quality development will be necessary to evaluate whether and when stemwood production in EHI treatments surpasses that observed in the ELO treatment. Further research is needed to explore to what extent later thinnings in the ELO treatment might be able to enhance birch growth production to levels projected for EHI treatments and produce birch sawtimber with potentially better quality.

Literature Cited

ALBAN, D.H., D.A. PERALA, M.F. JURGENSEN, M.E. OSTRY, AND J.R. PROBST. 1991. *Aspen ecosystem properties in the Upper Great Lakes.* US For. Serv. Res. Pap. NC-300. 47 p.

CONOVER, D.F., AND R.A. RALSTON. 1959. Results of crop-tree thinning and pruning in northern hardwood stands after nineteen years. *J. For.* 57:51–557.

DELLA-BIANCA, L. 1975. An intensive cleaning of mixed hardwood saplings—10-year results from the southern Appalachians. *J. For.* 73:25–28.

DWYER, J.P., AND K.E. LOWELL. 1988. Long-term effects of thinning and pruning on the quality, quantity, and value of oak lumber. *North. J. Appl. For.* 5:258–260.

EK, A.R. 1985. A formula for the total cubic foot stem volume of small trees in the Lake States. *North. J. Appl. For*. 2:3.

ERDMANN, G.G., R.M. GODMAN, AND R.R. OBERG. 1975. *Crown release accelerates diameter growth and crown development of yellow birch saplings.* US For. Serv. Res. Pap. NC-117. 9 p.

EYRE, F.H., AND W.M. ZILLGITT. 1953. *Partial cuttings in northern hardwoods of the Lake states.* USDA Tech. Bull. 1076. 124 p.

GEVORKIANTZ, S.R., AND L.P. OLSEN. 1955. *Composite volume tables for timber and their application in the Lake States.* USDA Tech. Bull. 1104. 51 p.

GILBERT, A.M., AND V.S. JENSEN. 1958. *A management guide for northern hardwoods in New England.* US For. Serv., NE For. Exp. Stn. Pap. NE-112. 22 p.

GODMAN, R.M., AND D.A. MARQUIS. 1969. Thinning and pruning in young birch stands. P. 119–127 in *Birch symposium proc.* Larson, N.H.E. (ed.). US For. Serv., Northeastern For. Exp. Stn.

GRAHAM, J.S. 1998. Thinning increases diameter growth of paper birch in the Susitna Valley, Alaska: 20 year results. *North. J. Appl. For.* 15:113–115.

HEITZMAN, E., AND R.D. NYLAND. 1991. Cleaning and early crop-tree release in northern hardwoods: A review. *North. J. Appl. For.* 8:111–115.

LABONTE, G.A., AND R.J. LESO. 1990. Cleaning paper birch in a birch-aspen stand in Maine: A 34-year case history. *North. J. Appl. For.* 7:22–23.

LABONTE, G.A., AND R.W. NASH. 1978. Cleaning and weeding paper birch—A 24-year case history. *J. For.* 76:223–225.

LEAK, W.B., AND D.S. SOLOMON. 1997. Long-term growth of crop trees after release in northern hardwoods. *North. J. Appl. For.* 14:147–151.

LUNDGREN, A.L., AND W.A. DOLID. 1970. *Biological growth functions describe published site index curves for Lake States timber species.* US For. Serv. Res. Pap. NC-36. 9 p.

MARQUIS, D.A. 1967. *Clearcutting in northern hardwoods: Results after 30 years.* US For. Serv. Res. Pap. NE-85. 13 p.

Marquis, D.A. 1969. *Thinning in young northern hardwoods: 5-year results.* US For. Serv. Res. Pap. NE-139. 21 p.

Marquis, D.A., D.S. Solomon, and J.C. Bjorkbom. 1969. *A silvicultural guide for paper birch in the Northeast.* US For. Serv. Res. Pap. NE-130. 47 p.

Marquis, D.A., R.L. Ernst, and S.L. Stout. 1984. *Prescribing silvicultural treatments in hardwood stands of the Alleghenies.* US For. Serv. Gen. Tech. Rep. NE-96. 101 p.

Miller, G.W. 2000. Effect of crown growing space on the development of young hardwood crop trees. *North. J. Appl. For.* 17:25–35.

Miner, C.L., N.R. Walters, and M.L. Belli. 1988. *A guide to the TWIGS program for the North Central United States.* US For. Serv. Gen. Tech. Rep. NC-125. 105 p.

Myers, R.H. 1990. *Classical and modern regression with applications.* Duxbury Press, Belmont, CA. 488 p.

Niemistö, P. 1995. Influence of initial spacing and row-to-row distance on the crown and branch properties and taper of silver birch (*Betula pendula*). *Scand. J. For. Res.* 10:235–244.

Ohmann, L.F., H.O. Batzer, R.R. Buech, D.C. Lothner, D.A. Perala, A.L. Schipper, Jr., and E.S. Verry. 1978. *Some harvest options and their consequences for the aspen, birch, and associated conifer forest types of the Lake States.* US For. Serv. Gen. Tech. Rep. NC-48. 34 p.

Perala, D.A., and A.A. Alm. 1989. Regenerating paper birch in the Lake States with the shelterwood method. *North. J. Appl. For.* 6:151–153.

Perala, D.A., and A.A. Alm. 1990. Regeneration silviculture of birch: A review. *For. Ecol. Manag.* 32:39–77.

Peterson, E.B., N.M. Peterson, S.W. Simard, and J.R. Wang. 1997. *Paper birch manager's handbook for British Columbia.* B.C. Min. For., Victoria, B.C., Canada. 134 p.

Ramsey, F.L., and D.W. Schafer. 1997. *The statistical sleuth.* Duxbury Press, Belmont, CA. 742 p.

Safford, L.O., J.C. Bjorkbom, and J.C. Zasada. 1990. Paper birch. p. 158–171 in *Silvics of North America. 2. Hardwoods.* Burns, R.M., and B.H. Honkala (tech. coords). US For. Serv. Agric. Handb. 654.

Safford, L.O. 1983. *Silvicultural guide for paper birch in the Northeast (revised).* US For. Serv. Res. Pap. NE-535. 29 p.

SAS Institute. 2002. *SAS Release 9.1.* SAS Institute Inc., Cary, NC.

Schuler, T.M. 2006. Crop tree release improves competitiveness of northern red oak growing in association with black cherry. *North. J. Appl. For.* 23:77–82.

Simard, S.W., T. Blenner-Hassett, and I.R. Cameron. 2004. Pre-commercial thinning effects on growth, yield, and mortality in even-aged paper birch stands in British Columbia. *For. Ecol. Manag.* 190:163–178.

Smith, H.C., and N.I. Lamson. 1983. *Precommercial crop-tree release increases diameter growth of Appalachian hardwood saplings.* US For. Serv. Res. Pap. NE-534. 7 p.

Trimble, G.R., Jr. 1973. *Response to crop tree release by 7-year old stems of yellow poplar and black cherry.* US For. Serv. Res. Pap. NE-253. 10 p.

Voorhis, N.G. 1990. *Precommercial crop-tree thinning in a mixed northern hardwood stand.* US For. Serv. Res. Pap. NE-640. 4 p.

Wright, H.E., Jr., L.A. Mattson, and J.A. Thomas. 1970. *Geology of the Cloquet quadrangle, Carlton County, Minnesota.* Minnesota Geological Survey GM-3, St. Paul, MN. 30 p.

Zasada, J.C. 2002. *Birch and birch bark.* Univ. of Minn. Ext. Serv., St. Paul, MN; Available online at www.extension.umn.edu/specializations/environment/components/birchbark1.html; last accessed Nov. 28, 2006.