Five-year Growth Response of a 41-year-old Yellow Birch Stand to Commercial Thinning

Alexandre Morin-Bernard, François Guillemette, and Steve Bédard[1]

Abstract.—Yellow birch (*Betula alleghaniensis* Britt.) is the second most harvested hardwood species in Quebec. Hardwood stands harboring this species are likely to yield high value products, and their proximity to inhabited regions facilitates a more intensive silviculture. Yet, little is known about the effects of silvicultural treatments such as commercial thinning on stands composed mostly of yellow birch. We set up an experiment in a 41-year-old yellow birch stand that arose after a clearcutting in 1971. The experimental design comprises four treatments: a control (no intervention); and light, moderate, and heavy commercial thinnings. After 5 years, results show that the thinnings had no significant effect on the net growth in basal areal of the stand. The treatments mostly led to an increase in the proportion of yellow birch and crop trees in the stand following the harvest targeting aspens and other less desired species. The smaller diameter trees near the trails showed the highest diameter growth response to the thinnings.

INTRODUCTION

Yellow birch (*Betula alleghaniensis* Britt.) is the second most harvested hardwood species in Quebec. The market value of its premium quality lumber is excellent (CRIQ 2002). In the past, selective harvesting aimed at removing the most valuable trees, as well as difficulties related to its regeneration, have led to a decrease in the abundance of quality yellow birch trees (Boulet 2015). The proximity of yellow birch stands to inhabited regions and sawmills offers the opportunity to practice a more intensive silviculture in these stands.

Previous work from Robitaille et al. (1990) has shown that clearcutting in a sugar maple (*Acer saccharum* Marsh.)-yellow birch stand can promote the return of yellow birch when accompanied by sufficient soil disturbance. This work also confirmed that precommercial thinning provides an advantage for yellow birch over competing species by having a marked increasing effect on sapling diameter growth. Similarly, in order to promote the growth of better quality trees and allow them to reach more rapidly the diameter necessary for the production of high value lumber, commercial thinning (referred hereafter as thinning), may be an appropriate treatment. Commercial thinning is an intermediate partial cutting conducted in even-aged stands when a portion of the stems has reached a relative commercial maturity. The reduction of stand density allows growing space and resources to be reallocated to remaining trees (Laflèche et al. 2013, Nyland 2002). In hardwood stands, the main objective is to promote the growth of better quality trees so that they reach their financial maturity diameter (45 cm; Guillemette 2016) more rapidly.

Yet, little is known about the effects of silvicultural treatments such as commercial thinning on stands composed mostly of yellow birch. Since their abundance is limited, very few studies have empirically investigated the quantitative effects of mechanized thinning in even-aged yellow birch stands that are approximately 40 years old and to our knowledge, none has been conducted in a similar site. A more intensive, even-aged silvicultural regime is however likely to allow the

[1] PhD Student, Lecturer (AMB), Université Laval, 2425 rue de la Terrasse, Québec, QC G1V 0A6; Hardwood Silviculture Researchers (FG, SB), Gouvernement du Québec, Ministère des Forêts, de la Faune et des Parcs, Direction de la recherche forestière, Québec, QC. AMB is corresponding author: to contact, call 418-264-3265 or email alexandre.morin-bernard.1@ulaval.ca.

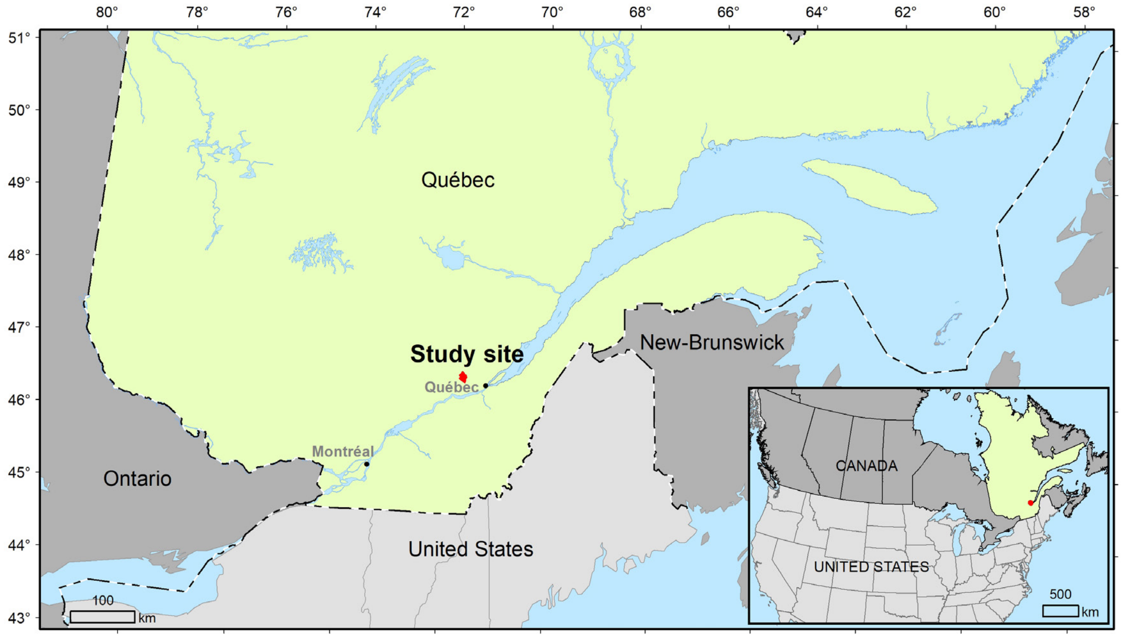

Figure 1.—Location of the study site.

production high quality and high valued lumber. The objective of this study was therefore to determine the effects of commercial thinning on basal area (BA) increment of crop trees and stand-level production in a 40-year-old yellow birch stand.

MATERIALS AND METHODS

Study Site

The experimental site is located 40 km northwest of Quebec City, Canada (lat. 46° 52' N., long. 71° 39' W.; Fig. 1). This area is in the southernmost ecological region of the eastern balsam fir-yellow birch bioclimatic subdomain (Saucier et al. 1998). Stands of balsam fir (*Abies balsamea* L.) and yellow birch are the most frequently encountered. However, the region benefits from a relatively mild climate; the long and regular slopes are colonized by maple stands, in which the main companion species are yellow birch and American beech (*Fagus grandifolia* Ehrh.). The mean annual temperature is 2.5 °C and the mean annual precipitation is approximately 1,200 mm (Blouin and Berger 2003).

The 24-ha site was established in 2012 in a yellow birch stand that arose after a clearcutting in 1971. In the past, the site has hosted an experimental setup established to monitor the effects of a precommercial thinning conducted in 1981 (Robitaille et al. 1990). The potential effect of this earlier experiment in the present study was isolated through the experimental blocks. Thus, all treatments in the same experimental block in the 2012 setup had received the same precommercial thinning treatment in 1981. The current setup includes seven complete blocks each comprising four square or rectangular-shaped experimental units, having an area of 1000 m^2 (0.1 ha). Before treatment, between 46.3 and 63.7 percent of the unit's BA was occupied by yellow birch, while quaking aspen (*Populus tremuloides*) accounted for 16.5 to 31.2 percent of the BA (Table 1). The quadratic mean diameter was 16.6 cm.

Table 1.—Average dendrometric characteristics and species composition by treatment and time of survey: merchantable basal area (BA) and stand density, quadratic mean d.b.h. (QMD) and species abundance

Treatment	Survey	BA	Density	QMD	Species* (% of BA)				
		($m^2 \cdot ha^{-1}$)	($trees \cdot ha^{-1}$)	(cm)	YB	SM	QA	Other	NCOM
Control	Before	21.2	1,077	16.6	57.2	3.2	21.1	9.9	8.7
	After	21.2	1,079	16.6	57.1	3.2	21.2	9.8	8.6
	5 years	23.2	1,009	18	62.8	3.7	20.6	10.1	2.8
Light thinning	Before	22	1,104	16.6	63.7	4.9	16.5	8.1	6.7
	After	14.4	713	16.8	68.9	5.4	12	9.3	4.3
	5 years	16.8	721	17.9	72.7	6.1	10.8	9.1	1.2
Moderate thinning	Before	22.7	1,130	16.7	58.2	3.4	25.2	6.9	6.3
	After	11.9	593	16.9	71.4	3.8	14.9	6.4	3.6
	5 years	14.6	653	17.7	77.3	4.7	11	5.6	1.4
Heavy thinning	Before	22	1,099	16.6	46.3	7.4	31.2	8.5	6.6
	After	9.6	499	16.5	66.4	9.4	14.6	7.7	1.9
	5 years	12.3	557	17.5	70.1	10.5	10.3	8.5	0.6

*YB = yellow birch, SM = sugar maple, QA = quaking aspen, Other = other commercial species, NCOM = Noncommercial hardwood species.

Four treatments—that is a heavy thinning, a moderate thinning, a light thinning, and a control—were randomly assigned among the experimental units of each block. The heavy thinning targeted a residual BA of 8.8 $m^2 \cdot ha^{-1}$, while the target residual BA for the moderate and light thinnings was 12.5 $m^2 \cdot ha{-1}$ and 15.4 $m^2 \cdot ha^{-1}$, respectively. These residual BA targets for the heavy and light thinnings corresponded respectively to the minimum density threshold that should be maintained in a stand (C-line) and the optimal density to promote overstory growth (B-line), according to the density management diagram of Leak et al. (2014). The moderate intensity treatment represents an intermediate situation.

Data Collection, Marking and Harvest Operations

Measurements were carried out before cutting (summer 2012), after cutting (fall 2012), and 5 years after cutting (fall 2017). For all trees with a diameter at breast height (d.b.h.) of 91 mm or greater, we recorded the species, tree health condition, d.b.h. and canopy position class. Among trees of the desired species, yellow birch, paper birch (*Betula papyrifera* Marsh.), sugar maple, red spruce (*Picea rubens* Sarg.), and white spruce (*Picea glauca* (Moench) Voss), crop trees were identified based on criteria related to the social status, vigor class, branching structure, and quality. Crop trees to be retained were marked, including in the control units, to allow comparing the increment of marked and nonmarked trees. Crop trees were chosen considering an average spacing of 8, 10, or 14 m depending on the targeted residual BA. An average spacing of 10 m was used for the control plots. The density of marked trees was 194, 144, and 64 $trees \cdot ha^{-1}$ for the heavy, moderate and light thinning treatments respectively, and 129 $trees \cdot ha^{-1}$ for control. Harvesting was carried out through the cut-to-length harvesting system, using a harvester with a processing head and a forwarder for the skidding of the 2.5 m long logs (Fig. 2). The harvesting guidelines comprised the establishment of 4.5 m trails 20 m apart, and the harvesting of the two largest competitors of each marked trees. Harvest of aspen trees was indirectly prioritized since this species was not one of the desired species and aspen stems were often larger than that of other species. Therefore, in some cases, the harvesting of the larger aspen trees resulted in thinning the stand from above.

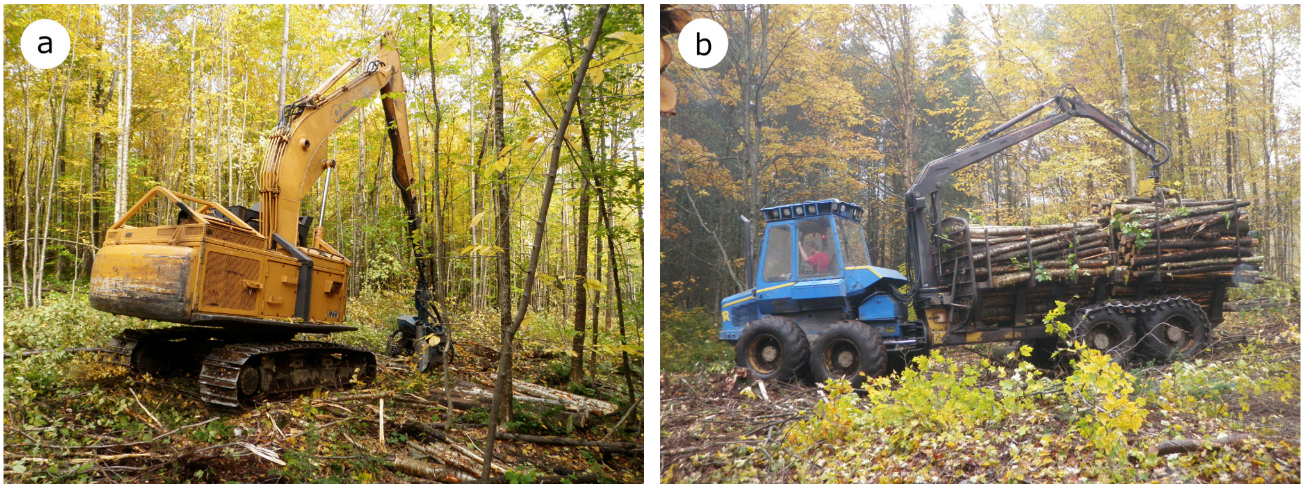

Figure 2.—Machinery used for harvesting: (a) harvester with a processing head; (b) forwarder. Courtesy photo by François Guillemette/MFFP, used with permission.

Data Processing and Statistical Analysis

BA ($m^2 \cdot ha^{-1}$) data were summed at the stand level according to the components of periodic annual increment, as proposed by Erdmann and Oberg (1973), that is the survivor growth, ingrowth, mortality, gross growth and net growth. Increments were calculated from the d.b.h. measurements.

To investigate the presence of a significant effect of the treatments ($p < 0.05$), we performed analyses of variance on the stand-level components of periodic annual increment in BA. Analyses were also conducted to investigate the effect of the treatments on the diameter increment at the tree level. The treatment was specified as a fixed effect. The block was considered as a random effect in the case of stand-level analyses, whereas for tree-level analyses, the experimental unit was considered as a random effect. The analyses were performed using packages *lme4* (Bates et al. 2015) and *emmeans* (Lenth et al. 2018) in the R programming environment (version 3.5.1, R Core Team 2018).

We divided the trees into three d.b.h. classes (10–12 cm, 14–16 cm, 18 cm and greater) in order to assess the effect of treatment on diameter growth. These classes were chosen in order to divide the population in groups of similar size. When a significant effect of one of the explanatory variables was detected, multiple comparisons were conducted using Tukey's test. The postulates of homogeneity of variance and normality of residuals were verified visually. Only one variable, ingrowth, required a logarithmic transformation. For this variable, we performed the analysis of variance as well as the multiple comparisons using the transformed variable, but we present the results using the untransformed data as for all other variables.

RESULTS

Pre- and Post-Harvest Stand Characteristics

Prior to harvesting, mean merchantable BA ranged from 21.2 to 22.7 $m^2 \cdot ha^{-1}$ depending on treatment (Table 1). The mean basal area removed was 7.6 $m^2 \cdot ha^{-1}$, 10.8 $m^2 \cdot ha^{-1}$, and 12.4 $m^2 \cdot ha^{-1}$, respectively, for the light, moderate, and heavy thinnings. BA after thinning was 14.4 $m^2 \cdot ha^{-1}$, 11.9 $m^2 \cdot ha^{-1}$, and 9.6 $m^2 \cdot ha^{-1}$, respectively, for the three thinning intensities. The achieved residual BAs were similar to that targeted, although a little lower than expected for the light thinning and a little higher than expected for the heavy thinning. In the lightly thinned experimental units, mean density was reduced by 35 percent, while it was reduced by 47 percent in the moderate intensity

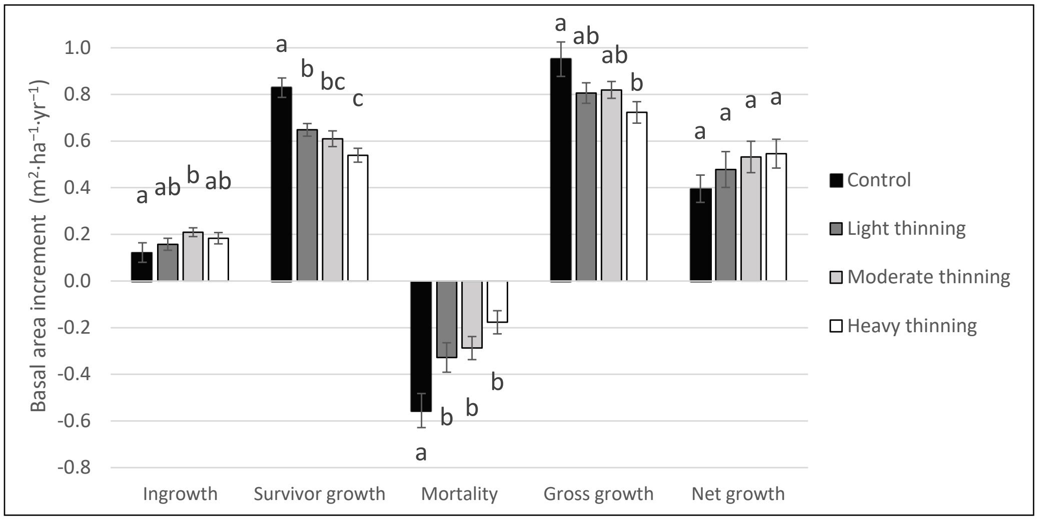

Figure 3.—Basal area increment for the first 5-year period after harvesting, by treatment. Error bars correspond to the standard error. Differing letters indicate significant differences among treatments.

thinning and by 55 percent in the heavy thinning (Table 1). The quadratic mean diameters were similar in all treatments, before and after thinning, ranging from 16.5 to 16.9 cm.

Treatments resulted in an immediate increase of 5.2 to 20.1 percentage points in the proportion of BA occupied by yellow birch, which averaged 66.4 to 71.4 percent of total merchantable BA after treatment. Five years later, yellow birch accounted for 70.1 to 77.3 percent of BA in thinned units, but only 62.8 percent in control units. Priority harvesting of trembling aspen, reaching 15 to 33 $m^3 \cdot ha^{-1}$, considerably reduced its presence in treated units. Whereas this species occupied 16.5 to 31.2 percent of the BA before treatment, it represented only 10.3 to 11 percent of the total merchantable BA 5 years after treatment, whereas it still occupied 20.6 percent of the BA in the control plots. Noncommercial hardwoods, represented mainly by pin cherry (*Prunus pensylvanica* L. f.), occupied 6.3 to 8.7 percent of the BA before cutting. However, the presence of these species had significantly decreased 5 years after treatment (from 0.6 to 2.8 percent of BA), including in the control units.

Stand-level Growth

Net BA growth only varied slightly between treatments, reaching 0.48 to 0.55 $m^2 \cdot ha^{-1} \cdot year^{-1}$ in the treated plots, and 0.40 $m^2 \cdot ha^{-1} \cdot year^{-1}$ in the control (Fig. 3). An examination of the components of stand growth provides insight into the effect of treatments on growth dynamics in the experimental units. For instance, survivor growth was significantly different among treatments ($p <$ 0.001; Table 2) and was greater for control than thinned units ($p < 0.001$). Among treated plots, the survivor growth was greater in the low intensity treatment than in the heavy thinning treatment

Table 2.—Results of analyses of variance on the effect of treatments on the components of five-year periodic increment in basal area. P-values indicating a significant effect are shown in bold.

Variable	DF num*	DF den*	F-test values	p-values
Net growth	3	18	2.19	0.125
Survivor growth	3	18	30.1	**<0.001**
Ingrowth	3	18	3.47	**0.038**
Gross growth	3	18	4.47	**0.016**
Mortality	3	18	7.24	**0.002**

*DF num = numerator degrees of freedom; DF den = denominator degrees of freedom

Table 3.—Annual increment in diameter for each treatment, by species and d.b.h. class

Species	d.b.h class	d.b.h. annual increment (mean ± standard error, mm·yr^{-1})			
		Control	Light	Moderate	Heavy
Yellow birch	10-12 cm	2.0 ± 0.1	3.2 ± 0.2	3.3 ± 0.2	4.2 ± 0.3
	14-16 cm	3.3 ± 0.1	4.0 ± 0.2	4.5 ± 0.2	4.8 ± 0.4
	18+ cm	5.0 ± 0.2	5.1 ± 0.2	5.5 ± 0.2	5.8 ± 0.2
All species	10-12 cm	1.9 ± 0.1	3.1 ± 0.2	3.2 ± 0.2	3.8 ± 0.2
	14-16 cm	3.1 ± 0.1	3.6 ± 0.2	4.2 ± 0.2	4.4 ± 0.3
	18+ cm	4.4 ± 0.2	4.8 ± 0.2	5.2 ± 0.2	5.4 ± 0.2
	All	3.1 ± 0.1	3.8 ± 0.1	4.2 ± 0.1	4.5 ± 0.1
Marked	All	4.6 ± 0.2	5.7 ± 0.3	5.3 ± 0.2	5.6 ± 0.2
Nonmarked	All	2.9 ± 0.1	3.4 ± 0.1	3.8 ± 0.1	3.6 ± 0.2

($p = 0.033$). The ingrowth also varied by treatment ($p = 0.038$), but in the opposite direction than survivor growth; it was greater in treated units than in the control, although multiple comparisons revealed a significant difference only between the moderate thinning and the control ($p = 0.033$). Gross growth, the sum of survivor growth and ingrowth, varied by treatment ($p = 0.016$; Table 2) and was significantly greater in the control than in the heavy thinning ($p = 0.005$), with a difference of 0.23 $m^2 \cdot ha^{-1} \cdot year^{-1}$ (Fig. 3). Finally, mortality also varied significantly between treatment ($p = 0.002$; Table 2). Mortality was significantly higher in the control than in the heavily ($p = 0.001$) and moderately thinned ($p = 0.023$) units, but that was not true for the light thinning ($p = 0.061$).

Tree-level Growth

The effect of thinning on diameter growth of residual trees depended on the thinning treatment as well as the d.b.h. of residual trees. Compared to the control, thinning increased diameter growth of residual trees only for trees in the d.b.h. classes 10 to 12 cm and 14 to 16 cm in the heavy thinning treatment ($p < 0.05$).

Tree diameter increment was different ($p < 0.05$) among the d.b.h. classes for all treatments but the 10 to 12 cm and 14 to 16 cm d.b.h. trees in the heavy thinning ($p = 0.051$). There was no significant effect of the treatment on the growth of trees with a d.b.h. of 18 cm and above ($p = 0.112$), which showed a mean increment of 4.8 ± 0.1 mm-year^{-1} (Table 3). The diameter increments of trees in the 10 to 12 cm and 14 to 16 cm d.b.h. classes were significantly different ($p \leq 0.023$) whether they were located in the heavy thinned units (3.8 ± 0.2 mm·yr^{-1} and 4.4 ± 0.3 mm·yr^{-1}) or in the control (1.9 ± 0.1 mm·yr^{-1} and 3.1 ± 0.1 mm·yr^{-1}). The conclusions of the statistical tests were the same whether we considered only yellow birch or trees from all species.

DISCUSSION

Influence of Thinning Intensity on Stand Level Net Growth

The net growth measured in the thinned experimental units was not significantly different from that measured in the control units. Compared to the control, the heavy and moderate thinning treatments resulted in reduced mortality ($p < 0.05$), while the moderate thinning also increased ingrowth ($p < 0.05$). These effects combined with the increase in diameter growth of the residual trees compensated for the reduced number of trees in the thinned stands. Although these results suggest that greater cumulative yields will indeed be achieved in the thinned units by the end of the rotation (Nyland 2002), they contrast with findings of other studies that also concluded to a significant increase in net growth consecutively to thinning (Erdmann and Oberg 1973, Leak and Yamasaki 2012, Pothier 1996). A similar study from Bedard et al. (2018) recorded a 5-year post-thinning net growth ranging between 0.63 and 0.71 $m^2 \cdot ha^{-1} \cdot yr^{-1}$ with various thinning intensities, although the net growth increment in the control was almost identical to that found in the present study (0.39 $m^2 \cdot ha^{-1} \cdot yr^{-1}$). However, stands studied as part of the present work differs in age, site, geographic location, and species composition. The site studied by Bedard et al. (2018) had a notable proportion of BA in yellow birch (21.7 to 31.7 percent), but was dominated by sugar maple. In our study, the growth gain of survivors in thinned units was lower than in Bedard et al. (2018), and the decrease in mortality following treatments was also lower. This difference in survivor growth may be due to the presence of aspen trees in a dominant canopy position in our experimental units before treatment. These trees, whose d.b.h. increases rapidly at this age, were harvested first during the thinning. Marquis and Ernst (1991) had already observed that the removal of dominant trees could lead to a reduction in net increment in the stand. The net growth measured in the control plots remains higher than what was observed by Pothier (1996) over a 20-year period in a sugar maple stand in the same area where the net increment in the control only reached 0.05 $m^2 \cdot ha^{-1} \cdot yr^{-1}$. However, the stands were 50 years old, and both the BA and mean d.b.h. were greater.

Influence of Thinning Intensity on the Tree-level Growth

The effect of thinning intensity on the average d.b.h increase was not significant for trees in the larger d.b.h. class. Nevertheless, these results confirm that yellow birch can respond to thinning if the opening is sufficient. Erdmann and Peterson (1972) had already observed the responsiveness of yellow birch to thinning in northern Michigan, in the 3 years following treatment. Their study site was located in a 40-year-old even-aged stand dominated by yellow birch. Density, BA, and average d.b.h. before treatment were comparable to that of our study. The greatest increase in d.b.h. was observed after the highest intensity harvest, which involved the removal of all competitors whose crowns were within a 4.5-m radius of the selected tree. The growth gain was proportional to the intensity of the removal, as we also observed, although in our case the differences between the three intensities were not significant. In contrast, the maximum d.b.h. increment measured by Erdmann and Peterson (1972) was nearly 8 mm in a single year, which is greater than the maximum 5-year mean value of 5.7 $mm \cdot yr^{-1}$ that we observed. Although our data showed that growth gain tends to increase with increasing thinning intensity, we were unable to conclude from the results of our statistical analysis. A potential explanation is that the clearing method was the same for all treatments, which was to harvest the two largest competitors of the marked tree. Thus, the increase in thinning intensity was rather an increase in the number of trees cleared than an increased clearance of some trees. This aspect will need to be further analyzed following the planned 10-year post-treatment measurement. It would have been interesting to test the effect of several clearance intensities around the future trees. However, the constraint of operational harvesting and mechanized felling prevented us from doing so. Indeed, it was difficult to harvest trees on the opposite side of the marked trees without risking damage to its neighbors.

Influence of Diameter and Social Status on Tree-level Growth

Our conclusions regarding the effect of d.b.h. class and social status on diameter increment are similar to that of Erdmann and Peterson (1972), who stated that the response to thinning is greater in intermediate trees than in codominant and dominant trees. Indeed, growth gains measured in thinned stands compared to the control stands were substantially lower for trees with d.b.h. of 18 cm and above and for marked trees than for trees in the lower d.b.h. classes. For the larger trees, the growth difference between treated and control stands were not statistically significant. This discrepancy could be explained either by the nature of the competition experienced or by the responsiveness of the cleared trees. First, it is possible that the larger trees, generally in a dominant or codominant position, still had sufficient access to light prior to treatment and experienced only a limited competition for sunlight and resources. Removal of neighboring trees would therefore have had only a limited effect. This hypothesis was proposed to explain the limited growth response of the larger trees after thinning in a Douglas-fir stand (Dodson et al. 2012). Secondly, it is possible that at 41 years of age, the ability of dominant and codominant yellow birches to respond promptly to thinning was not as strong as expected. Indeed, while strong responses to thinning were observed at 16, 35, and 40 years (Erdmann and Peterson 1972, Erdmann et al. 1975a, Ouimet et al. 2018), the response was rather minimal at 65 years (Erdmann et al. 1975b). Thus, yellow birch may lose its ability to respond promptly to thinning between 40 and 65 years of age.

Our results confirmed that, despite a lower response of larger diameter trees to thinning, they still contributed the most to the growth at the stand level. Other authors have made similar observations (Bedard et al. 2018, Erdmann and Peterson 1972). Although the absolute growth of dominant trees is greater than that of lower-story trees, the relative growth gain generally follows a trend of opposite direction (Marquis 1969, Miller 2000, Ward 1995). The significant effect seen for smaller diameter trees would therefore be attributable to a decline in competition, resulting in greater access to light for the remaining trees. This effect is particularly visible in trees located near logging trails. Indeed, their growth was significantly higher ($p \leq 0.01$, results not presented) than that of trees located more than 5 m from the trails. Consistent with the findings of Bedard et al. (2018), the significant difference observed between the growth of trees located within 5 m of the center of a trail and those located further away would be entirely attributable to this clearance. Finally, the observed gain in d.b.h. increment of residual trees in the treated units could be due to the retention of the most vigorous trees, whose increment is higher, during thinning. This hypothesis is supported by the fact that the increment of marked trees was significantly higher than that of nonmarked trees, even in control. Therefore, in the present study, thinning following tree marking effectively allowed to retain trees with a superior growth potential.

Since this study only includes data collected 5 years after thinning, the most pronounced benefits might not be seen until the next few years. Clearing could allow marked trees to develop their crowns, especially in density. Indeed, Erdmann and Peterson (1972) observed an increase in crown density in a large proportion of cleared yellow birch trees in the 3-year period following commercial thinning, resulting a d.b.h. increase. Although changes in crown density were not documented in this study, the increased photosynthetic capacity of these trees may also allow them to maintain their growth for a longer period than in the absence of treatment.

Implications for Management Practices

In the present study, results from the 5-year monitoring showed that commercial thinning mainly improved stand composition, increasing the proportion of yellow birch and crop trees consecutively to the priority harvesting of aspens and other unwanted species. In the studied yellow birch stand, crop trees appeared to suffer little from competition from shade intolerant species before treatment. In addition, the use of heavy machinery made it difficult to completely clear the crowns of marked trees. Thus, thinning resulted in only small gains in growth compared to a no-intervention control. In fact, the growth of the controls was still very good, especially for larger diameter and crop trees. The thinning could have been delayed for a few years without compromising stand quality and vigor. This would have increased the profitability of operations by obtaining a larger average harvest diameter. However, the probability of obtaining a lower growth response seems to increase with stand age.

In an intensive silviculture scenario, commercial thinning is normally carried out after precommercial thinning. Based on the short-term results from the present study and the scientific literature consulted, it seems that the growth response to commercial thinning of dominant yellow birch in young stands with an even-aged structure is of lesser magnitude than their response to precommercial thinning. Nonetheless, the results obtained still demonstrate the benefits of practicing of commercial thinning in a 40-year-old yellow birch stand. The primary focus of the intervention should be to improve stand composition as well as the relative importance of crop trees in the stand. The benefits for stand growth of a commercial thinning conducted later in the scenario appears to be more variable, and to be highly dependent on stand composition and age. Longer-term results from this experimental site will allow verifying how the benefits of commercial thinning change over time.

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