At Which Diameter Does Sugar Maple Reach Financial Maturity at the Northern Edge of its Range?

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Abstract.—Improving financial revenues from partial cuts in sugar maple (*Acer saccharum*) stands at the northern edge of the species' range involves harvesting trees that have reached their financial maturity size (i.e., the diameter at which their monetary value is greatest and beyond which there is no further gain). To establish the lumber value of each tree at the sawmill, a sample of 171 trees were measured, felled, bucked into logs, and sawn into boards. We estimated their value changes over 10 years using data from a network of permanent sample plots. The most vigorous and best quality maples started losing value at a diameter at breast height of 36 cm. Those belonging to the lowest grade and containing a potential sawlog increased in value, but only marginally. The low value of these trees makes the profitability of forest management challenging at the northern edge of sugar maple's range.

INTRODUCTION

Sugar maple (*Acer saccharum* Marshall) is one of the most abundant hardwood species in eastern North America (Godman et al. 1990). Its primary range extends from 35° to 48° of latitude North, from the state of Tennessee (United States) to the province of Quebec (Canada). Sustainable management of sugar maple for timber production is challenging at the northern edge of the species' range, due to high transportation costs and low timber quality (Guillemette and Bédard 2019). In this region, maple stands are managed using partial cuts to mimic the natural dynamics of individual tree mortality in these forests.

Historically, the demand for sugar maple sawlogs in this region was low. Recently, however, the lack of volume available in the south of Quebec forced sawing activities to move further north. Improving the financial revenues from partial cuts involves harvesting more high quality maple trees that have reached their financial maturity size (i.e., the diameter at which their monetary value is greatest, and beyond which there is no further gain) and fewer low quality trees with defects. Size at financial maturity has been defined for trees growing in the southernmost portion of the sugar maple management area in Quebec (Guillemette 2016). The objective of this study was to determine the financial maturity size for sugar maple at the northern edge of the species' range.

MATERIAL AND METHODS

Calculating tree financial maturity size for the needs of the sawmill industry requires estimating the monetary value of trees at the beginning and at the end of a growing period, in order to identify the diameter at which a tree's mean value begins to decrease. This analysis relies on a model to estimate the value of lumber according to a tree's diameter, which is applied to trees whose evolution has been monitored over a period of time. The main monitored variables are survival or death, diameter growth, and stem quality change.

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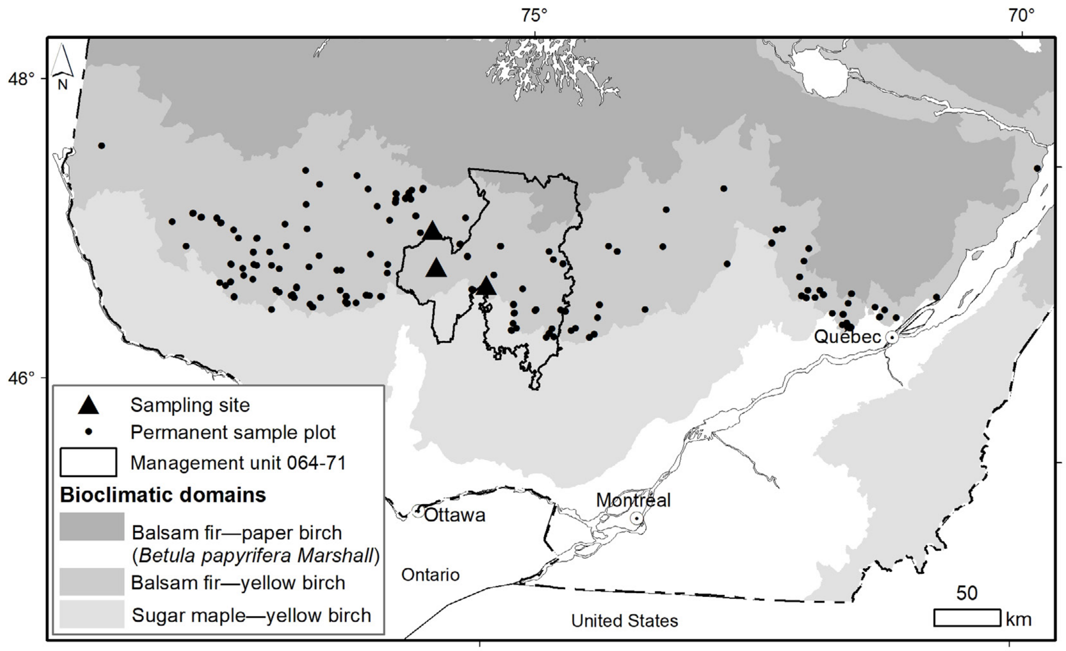

Figure 1.— Location of the permanent sample plots and the study sites within the balsam fir–yellow birch bioclimatic domain of the province of Quebec, and location of the management unit of interest.

Tree Value

We sampled 171 sugar maples in three northern sites located in or near a management unit of interest for the maple sawmill industry (Fig. 1). The sampling sites were located in the balsam fir (*Abies balsamea* [L.] Miller)–yellow birch (*Betula alleghaniensis* Britton) bioclimatic domain. In this northern territory, sugar maples are mostly located on top hills, while balsam fir and yellow birch dominate more mesic sites (Gosselin et al. 1998). Mean annual temperature varies from 0 to 2.5 °C, and mean annual precipitation ranges from 800 to 1,000 mm.

The studied trees were classified into four grades (A, B, C, and D, after MRNQ 1995), which correspond approximately to grades 1, 2, 3, and below-grade, respectively, in the system commonly used in the United States (Hanks 1976). This grading is established according to a tree's diameter at breast height (d.b.h., measured at a height of 1.3 m), length and number of defect-free sections on the surface of the second-worst face of the best 3.7 m log located on the butt log (first 5 m), and percent volume deduction for crooks, sweep, and rot within the log. Grades A (22 trees) and B (43 trees) have minimal d.b.h. thresholds of 39.1 and 33.1 cm, respectively, while grades C (80 trees) and D (26 trees) both have a minimal d.b.h. threshold of 23.1 cm. In this study, grade A and B trees were merged into an AB grade, both for simplicity and because grade A trees are relatively rare in the study area (Guillemette and Bédard 2019).

Once the trees were felled and bucked into logs, the 170 resulting sawlogs were sawn into 1,974 boards and blocks that were graded according to the NHLA (2007) classification. A complete tree-log-lumber tracking record was kept throughout the study, as described in detail in Bédard et al. (2018). Using the actual lumber trend prices for the study region (Table 1), we established the lumber value of each tree at the sawmill. We did not include the price of the unmeasured volumes for chips, sawdust, and bark.

Table 1.— Lumber trend prices according to grade and color (after NHLA 2007) estimated for sugar maple in the province of Quebec, Canada ($ CAD/MBF). MBF = thousand board feet; CAD = Canadian dollar. Data source: Bureau de mise en marché des bois, ministère des Forêts, de la Faune et des Parcs du Québec (Quebec's governmental timber marketing office). Currency conversion: $1 CAD = $0.82 US as of May 6, 2021.

Grade	Price according to color ($ CAD/MBF)	
	Sap	Regular
FAS & Selects	1,800	900
1C	1,325	700
2C	1,025	520
3C	875	475
3B	300	300
Central block	375	375

We calibrated a two-part conditional model (similar to that of Fortin et al. 2009) to estimate the average lumber value of a maple tree with a given d.b.h. and tree grade. In a first step, we estimated the probability of observing a sawlog in a given tree, and in a second step, we estimated the average value of lumber in this tree when at least one sawlog is sawn (analyses performed using the GLIMMIX and MIXED procedures, respectively; SAS Institute 2008). Finally, we calculated the mean lumber value in the tree by multiplying the probability of occurrence (first part) by the mean conditional value (second part) of the lumber in a tree.

Tree Value Change Over Time

To estimate the value change of each tree over a growth period, we used data from a network of permanent sample plots in the same bioclimatic domain and observed each tree's evolution as a function of its d.b.h., risk class, and tree grade. The risk class system aims to identify trees according to a gradient of mortality risk over the next cutting cycle based on the presence of defects on the tree (Boulet 2005). Trees were classified as moribund (M), surviving (S), growing to be conserved (C), or reserve stock (R) following a descending order of anticipated mortality risk: M trees are often characterized by the presence of a fungal infection, an abundant decay, or crown dieback; S trees are frequently associated with stem cracks or a small amount of decay; finally, C and R trees are considered sound and vigorous. C trees usually present some minor defects, such as a crook or sweep. In this study, C and R trees were merged into a CR class to simplify.

In the study area, measurements of risk class and tree grade were available since 2003 in Quebec's national forest inventory database (MFFP 2014), and since 2005 in datasets from experimental plots (Guillemette and Bédard 2019) and monitoring plots (Guillemette et al. 2017) of two study networks for selection cutting. From these data, we used a total of 2,000 sugar maple trees with a d.b.h. of 23.1 cm to 49.0 cm that were surveyed on average for 10 years (4 to 15 years) in 274 permanent plots (Fig. 1). Forty-seven percent of these trees were in a plot managed under a partial cutting system, mainly selection cutting.

We estimated the lumber value of sugar maple trees for every possible combination of d.b.h. class (2 cm increments from 24 cm to 48 cm), risk class (3 levels), and tree grade for lumber at the beginning and at the end of the growth period. We then calculated the mean annual change in lumber value for each combination. The limits of financial maturity for sugar maples belonging to the different combinations of risk classes and tree grades correspond to the points along the d.b.h. gradient where the trees begin to lose value. Because of model fit issues, the evolution of tree value according to initial d.b.h. was modeled using a regression spline effect with the HPMIXED procedure (SAS Institute 2008).

RESULTS

Tree Value

In the first part of the conditional model, the probability of observing a sawlog varied significantly between tree grades (P <0.0001, Fig. 2A), but not according to d.b.h. (P = 0.0696, not shown). To simplify and in the absence of a significant difference (P = 0.9953), we merged grades A and B. The fact that the random site effect was not significant (P = 0.1795) suggests that there is no major difference among the three studied sites. Grade AB trees had a probability of 83.5 percent to produce a sawlog, while the probability was down to 47.1 percent for grade C trees. As expected, a sawlog was rarely observed in D trees (below grade, 2.5 percent probability).

In the second part of the conditional model, the value of the lumber in a tree having a sawlog varied according to d.b.h. ($P < 0.0001$) and tree grade ($P < 0.0001$, Fig. 2B). Again, to simplify and in the absence of a significant difference ($P = 0.3921$), we merged grades A and B. We also merged grades C and D due to a lack of observations, as only one sawlog was observed in 26 grade D trees. The significance of the random site effect ($P < 0.0001$) suggests that an important portion of variability among the three studied sites remains unexplained.

Overall, the lumber value of a maple tree in our study varied greatly among grades (AB, C, or D) and according to d.b.h. (Fig. 2C). The highest mean lumber value reached \$109 CAD[2] (grade AB maple tree with a d.b.h. of 54 cm). Note that the highest overall lumber value in an individual tree (\$209 CAD) was found in a grade AB with a d.b.h. of 48 cm, while some trees with a similar d.b.h. and grade yielded no sawlog once felled, because internal decay was present and more prevalent than what was expected from assessing the standing tree.

Tree Value Change Over Time

The value of grade AB sugar maple trees with the highest mean lumber value (\$55 to 61 CAD) decreased over time independently of their risk class (Table 2, −0.8 to −5.0 percent/year). However, those with a d.b.h. of 34 cm in the CR risk class gained slightly in lumber value over a 10-year growth period (Fig. 3; 0.4 percent/year). On average, grade C trees had a low lumber value (\$10 to 13 CAD), and M trees of this grade lost lumber value over time (−3.0 percent/year). However, grade C maple trees in the lowest risk class (CR) generally increased their lumber value (4.4 percent/year), reaching a peak of 8.2 percent/year at a d.b.h. of 32 cm (Fig. 3). This size represents the d.b.h. threshold for grade C trees, which can reach grade B at a d.b.h. of 34 cm. For grade D trees, the increase in mean annual percent change in lumber value was great (27.8 to 82.6 percent/year), but had little impact overall, given the low value of these trees for lumber (< \$1 CAD).

[2] Canadian dollars

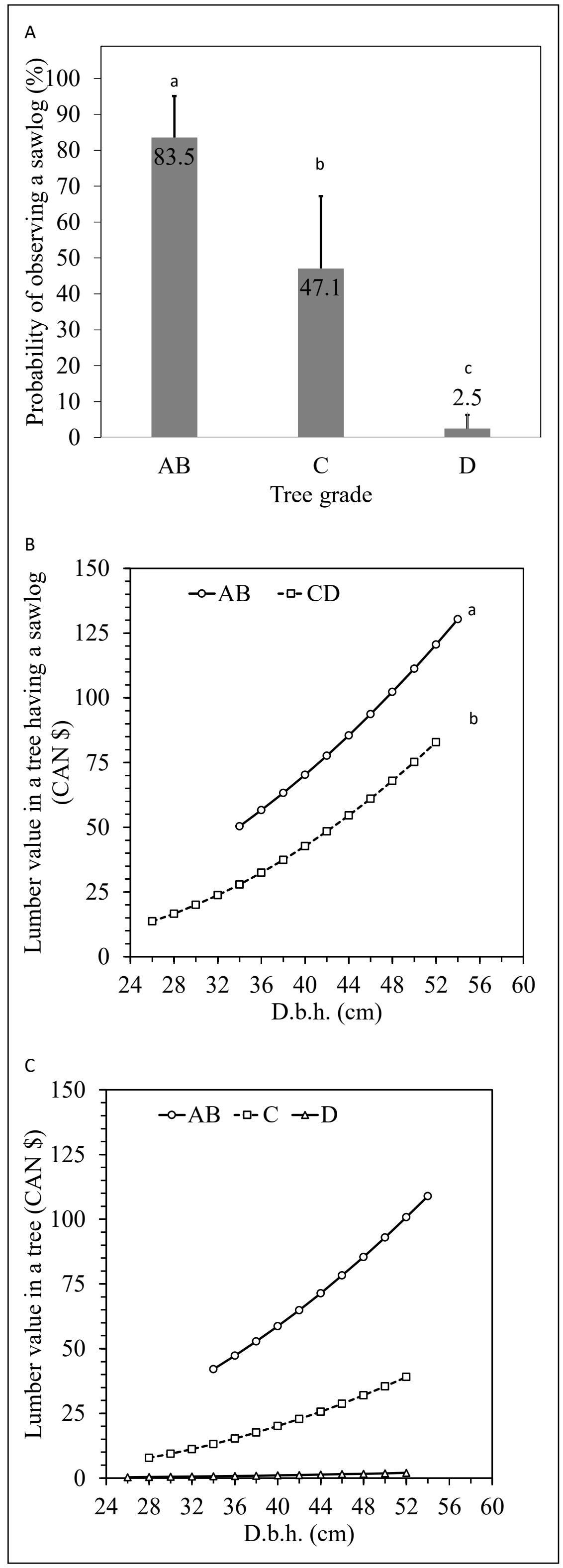

Figure 2.— Conditional model used to estimate the average lumber value of a maple tree for a given diameter at breast height (d.b.h.) and tree grade. (A) Part 1: Probability of observing a sawlog; (B) Part 2: Mean lumber value in a tree having a sawlog; (C) Conditional mean lumber value in a tree (probability × mean value in the presence of a sawlog). 1 cm = 0.4 inches. Currency conversion: \$1 CAD = \$0.82 US as of May 6, 2021.

Table 2.— Number of maple trees for which evolution was monitored, mean lumber value within a tree and mean annual percent change according to risk class and tree grade. Grades AB, C, and D are similar to U.S. grades 1 and 2, 3, and below-grade, respectively. Currency conversion: $1 CAD = $0.82 US as of May 6, 2021.

Risk class	Tree grade	Number of trees	Mean lumber value ($ CAD)	Mean annual change (%)
M (moribund)	AB	24	61.13	−5.0
	C	203	12.56	−3.0
	D	213	0.68	27.8
S (surviving)	AB	30	60.25	−3.0
	C	189	12.45	0.7
	D	85	0.57	63.8
CR (conserve or reserve)	AB	214	55.08	−0.8
	C	940	9.69	4.4
	D	102	0.52	82.6
All		2,000		

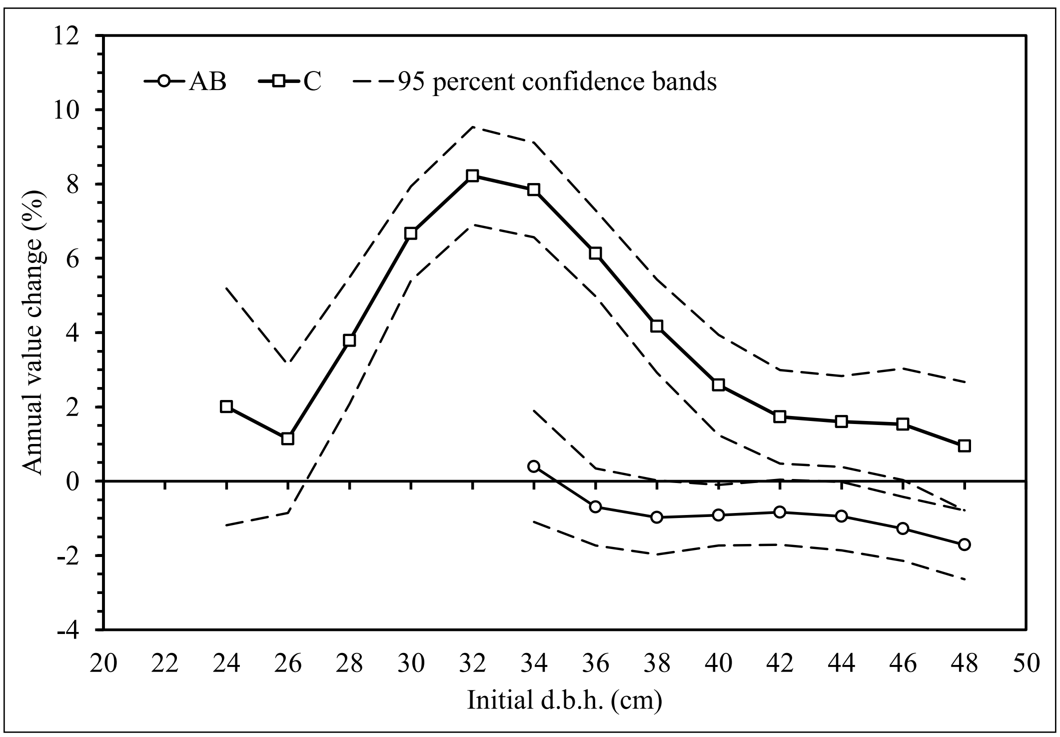

Figure 3.— Mean annual percent change in lumber value according to the initial diameter at breast height (d.b.h.) and tree grade (AB or C) for maple trees with the lowest risk class (CR, i.e., conserve or reserve). 1 cm = 0.4 inches.

DISCUSSION

Our results indicate that at the northern edge of sugar maple's distribution range, the most vigorous and high quality trees (i.e., those of the CR-AB class) reach financial maturity for a sawmill at a d.b.h. of 36 cm (Fig. 3). Larger trees lose their lumber value due to tree mortality or wood degradation, mainly through the development of decay or stem cracks (Burton et al. 2008). This result is not surprising, since vigorous and high quality trees are relatively rare on northern sites. In fact, only about 15 to 33 percent of sugar maples with a d.b.h. of 34 cm or more were graded as AB in this territory; further south, the average abundance of such trees could reach 60 percent (Guillemette and Bédard 2019). In Quebec's sugar maple bioclimatic domains (all located south of the balsam fir–yellow birch bioclimatic domain studied here), Guillemette (2016) reported d.b.h. values of 43 to 45 cm at financial maturity, depending on the region. These were similar to values suggested by Leak et al. (1987) across the states of New England and New York (i.e., 40 to 50 cm, depending on tree grade potential). Hansen and Nyland (1987) also reported a similar d.b.h. range in the state of New York. In our study, loss of value was also observed at any d.b.h. in other high quality trees (grade AB) belonging to the higher risk classes (M or S) (Table 3).

The value of vigorous maples in the lowest grade to possess a potential sawlog (grade C) increased up to a d.b.h. of almost 50 cm (Fig. 3). However, our data sampling was insufficient to provide a more precise estimate of the evolution of lumber value near this size. In the region studied, maple trees were rarer in these large d.b.h. classes, and most of them were in the higher risk classes (M or S).

In any event, despite some value gain in certain grade C maples, the value of these trees was quite low when considering sawmill profitability (Fig. 2C). A regional reference is the value of a net cubic meter of round wood. In this study, a maple tree with a d.b.h. of 46 cm yielded 1 m^3 of net round wood, on average, and grade C trees in the 34 to 48 cm d.b.h. range had a mean lumber value of \$29/m^3 CAD. Meanwhile, we estimate that supplying a hardwood sawmill from partial cuttings costs \$68/m^3 CAD (without stumpage fees), according to a cost survey (Groupe DDM 2020). Given these values, the revenues from sawdust, chips, bark, and pulp logs need to be relatively high to offset supplying costs. In contrast, the mean lumber revenue from grade AB maple trees was \$75/m^3 CAD, which is more realistic when aiming for sawmill profitability.

The main explanation for the low lumber value of grade C sugar maple trees harvested so far north is that only 47.1 percent of them produced a sawlog (Fig. 2A). For comparison, Fortin et al. (2009) observed the presence of a sawlog in 85 percent of the grade C maple trees in Quebec's sugar maple bioclimatic domains, a percentage similar to that of grade AB trees in both studies. Another reason for such a low lumber value comes from the dark coloration often present at the center of the maple trees. This "dark heart" is a serious concern because sugar maple wood is valued for its white "sap" color (Germain et al. 2015; Table 1). In the three sampled sites, the dark heart in the sawlogs covered 60 percent of the logs' diameter at the small end, on average, while in southern parts of the province, it usually ranges from 40 to 50 percent (Guillemette et al. 2021). In the 10 sites studied by Germain et al. (2015) in New York, this proportion ranged from 12 to 42 percent for trees graded 1 or 2 (the equivalent of grades A and B in our study, respectively).

A different source of lumber prices (e.g., HMR 2021[3]) would have led to a different evaluation of lumber revenues. However, this would have little impact on how this value evolves, and thus, on our evaluation of diameter at financial maturity. Indeed, Guillemette (2016) evaluated the effect of different sets of prices on the assessment of financial maturity size for yellow birch and concluded

[3] [HMR] Hardwood market report. 2021. https://hmr.com/ (accessed May 10, 2021).

that they yielded similar results. This could be explained by the fact that tree value evolution is mostly determined by mortality (which causes a very large loss of value), degradation of a surviving tree (moderate loss of value), and increase in diameter for surviving trees (small gain in value).

Management Implications

In our study, sugar maples located at the northern edge of the species' distribution range produced low-value lumber with little potential for improvement over time. As a result, the diameter at financial maturity of the best trees (grade AB in the risk class CR) for lumber production is small (36 cm). Consequently, for these maple stands, it is challenging to suggest appropriate silvicultural approach, and clearcutting should be considered. However, this scenario yields large volumes of pulpwood, and the absence of a large-enough pulpwood market in these northern areas reduces profitability. Thus, high-grading through a partial cut remains tempting, despite the well known problems associated with high-grading and diameter-limit cutting (see Kenefic and Nyland 2006). The main silvicultural challenge in these sites is to find a balance between harvesting the small amount of high value maple trees while keeping an acceptable growing stock, maintaining proper conditions for regeneration, and allowing enough time for forest stands to accumulate enough AB trees with a d.b.h. greater than 34 cm. The enhancement of the other functions of the forest, e.g., the nonmonetary values that these sugar maple stands might provide, would be an avenue to be further explored. Other ongoing research projects could provide a clearer view of potential solutions. However, we do not anticipate great potential for sugar maple lumber production in the study area for several decades, even if global warming improves growth conditions (Jain et al. 2021). The integration of these less profitable maple stands with the harvesting of adjacent more profitable stands is also an opportunity to consider.

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