

Logging Damage and Lumber Recovery Project – Stoke’s Study

Forestry Research Partnership project # 150-301

Progress Report, February 2006



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Introduction

This research project was conducted by Forintek Canada Corp., the Ontario Ministry of Natural Resources (OMNR) and the Tembec Forestry Research Partnership. The overall objective of the study was to evaluate growth response, lumber yield and products value of a hardwood stand one rotation after a selection cut. Analyses focussed on 1) Basal area growth of the stand after cut; 2) Individual tree growth rate in diameter and basal area for Sugar Maple and American Beech, 3) Lumber yield and products value for Sugar Maple and American Beech; 4) Relationships between logging damage, internal defect in the stem, lumber yield and wood product value.

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Objectives

The objectives of the project were to:

1. Evaluate stand growth response after a single tree selection cut;
2. Evaluate the effect of species, tree size, stem quality and damage severity on growth rates of individual trees after harvesting;
3. Compare volume yield and product recovery by species, tree size, stem quality and damage severity;
4. Evaluate total volume recovery by product type at the stand level;
5. Evaluate volume recovery by product type for a selection harvesting scenario at the stand level;
6. Establish relationships between wound size and internal defects 20 years following logging injuries;
7. Quantify the impact of multiple wounds on stem defects and, ultimately, identify a distance between wounds that seems critical.

Objectives 6 and 7 will not be directly addressed in the present report. Further analysis using CT scanner images will be analyzed and reported in the future.

Team composition

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Acknowledgements

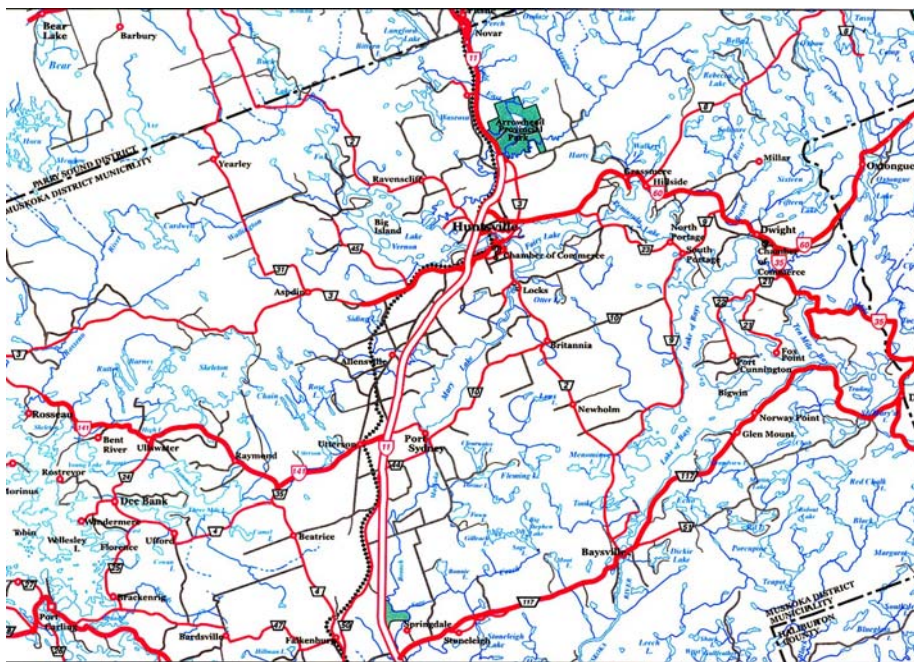
This study was initiated in 1983 by Dave Deugo and Rob Stokes whose vision and work are gratefully acknowledged. A special thank is addressed to every member of the OMNR staff involved at any point in the laborious data collection. Gary Raddy, Brian Bjornquist and Jim Rice were responsible for relocating and re-establishing the plots in the mid 90's. Without their efforts, the plots might have been lost due to the natural decay process of their central (wooden) poles. The 2003 harvest operations were carefully conducted by Gerald and Mark Cook who showed excellent professional skills coupled with a remarkable tolerance regarding research people attempts. Tony Zhang, Murray Woods, Al Stinson, and Bill Cole put their efforts together in a way that allowed the 2003 phase of the project to be funded and realized. Many reviewers provided helpful comments on previous versions of the present report and their collaboration was of great value. Finally, the author of this report wishes to address personal thanks to the following persons who were involved in the field work surrounding harvest operations and/or data compilation: Luc Bédard, Gilles Chauret, Lucy Emmott, Guillaume Giroud, Yves Giroux, François Lemay, Wayne Reid, and Scott Stinson.

Methods

Study site

Study site is located on crown lands in Parry Sound District near Huntsville, ON (figure 1). It is part of the Great Lakes St. Lawrence forest region which is characterised by well drained soils on granitic bedrock. Sugar Maple (*Acer saccharum*, Marsh.), American Beech (*Fagus grandifolia*, Ehrh.), Basswood (*Tilia Americana*, L.), Red and White oaks (*Quercus rubra*, L.; *Quercus alba*, L.), White ash (*Fraxinus americana*, Ehrh.), Yellow and White birches (*Betula alleghaniensis*, Britt.; *Betula papyrifera*, Marsh.) and Aspens (*Populus* sp.) are the deciduous species generally encountered in the region. Coniferous species comprise White and Red pine (*Pinus strobus*, L; *Pinus resinosa*, Ait.), White and Black spruce (*Picea glauca*, Moench.; *Picea mariana*, Mill.), Eastern hemlock (*Tsuga canadensis*, L.), Eastern cedar (*Thuja occidentalis*, L.) and Tamarack (*Larix laricina*, Du Roi) (OMNR, 1998).

Figure 1: Study site

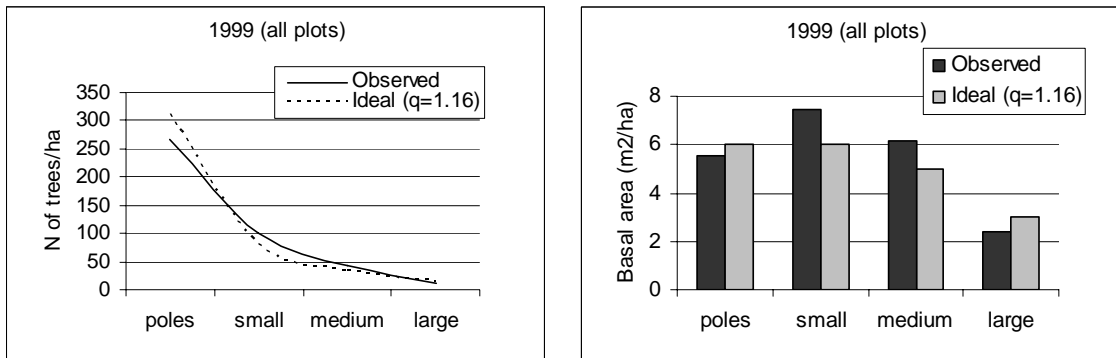


Stand description

The study stand is uneven-aged and dominated by Sugar Maple and American Beech. A single tree selection partial harvest done in fall and winter 1983-84 preceded the establishment of twelve experimental plots (each plot is 1256.64 m²). Tree marking had been done by the OMNR and harvesting by Weldwood of Canada Incorporated. Logs were skidded tree-length. The area was probably chosen as a study site because of an excessive amount of damage observed following the harvest. As specified by the OMNR (1996), the project was undertaken in an effort to determine the type(s) and extent of logging damage. The overall objective of the study was for the OMNR to become more aware of the long-term effects of irresponsible felling and extraction techniques on the future health, quality, productivity and value of forest stands (OMNR, 1996).

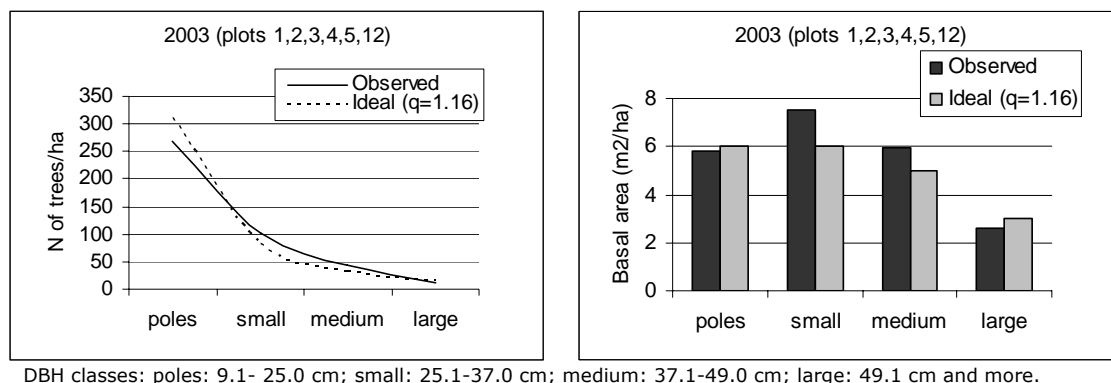
From 28.8 m²/ha before the 1983 cut, stand average basal area (BA) was reduced to 18.9 m²/ha after treatment (1983), representing a cutting intensity of about 35%. A post-harvest survey determined that 43% of the residual stems (or 29% of the residual BA) exhibited logging wounds to the bole or damage to roots and crown systems. The majority (88%) of wounded trees were poles (diameter at breast height (dbh) = 9.1 to 25.0 cm) or small sawlogs (25.1 to 37.0 cm at dbh). In addition, 42% of the forest floor was affected by skid trails (OMNR, 1996). The stand was measured again in 1999 (all plots) and on 6 of the plots in 2003 (plots 1 to 5 and 12). Stand structure (1999 and 2003) is presented in figures 2 and 3.

Figure 2: Stand structure in 1999 (all plots): 16 years post-harvest



DBH classes: poles: 9.1- 25.0 cm; small: 25.1-37.0 cm; medium: 37.1-49.0 cm; large: 49.1 cm and more.

Figure 3: Stand structure in 2003 (plots 1-5 and 12): 20 years post-harvest



Data compilation

Stand growth response was evaluated 1) sixteen years following selection harvesting in all plots, and 2) for the whole cutting cycle (20 years) in plots that were measured again in 2003-2004 (plots 1 to 5 and 12). Trees of all commercial species were grouped based on their health status at the beginning (1983) and at the end (1999 and 2003) of the growing period (table 1). This allowed for the evaluation of the contribution of ingrowth and survivor to BA increment and for the calculation of mortality. A tree was considered of merchantable size if it was at least 9.1 cm in dbh.

As presented in table 2, stand BA averaged 28.8 m²/ha and 18.8 m²/ha before and after the 1983 harvest (all plots); 21.5 m²/ha in 1999 (all plots) and 21.3 m²/ha in 2003 (plots 1 to 5, and 12). **After the initial harvest (1983), 18% of stand BA (plots 1 to 5, and 12) consisted of trees with adequate quality attributes known as acceptable growing stock (AGS).** As defined in the Ontario tree marking guide (2004), « AGS trees exhibit form an appearance that suggests they can reasonably be expected to contribute significantly to future crops in the form of vigorous, high quality stems » while « UGS trees are high risk and are expected to decline during the next cutting cycle. UGS trees may also be of poor form and/or low quality and cannot reasonably be expected to improve in quality ». **The proportion of AGS trees was 46% in 1999 (all plots) and 40% in 2003 (plots 1 to 5, and 12; figure 4).**

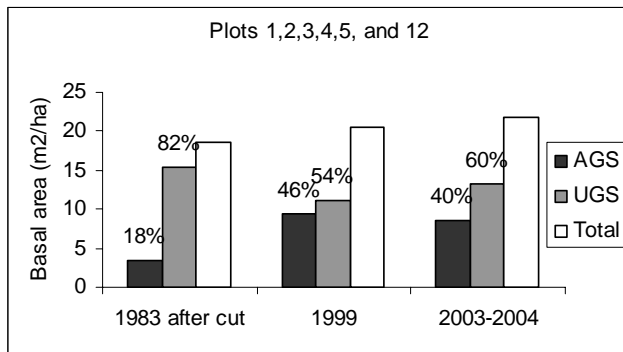
Table 1: Grouping method for the calculation of ingrowth, survivor growth and mortality

Initial status	Final status	Group
Alive, dbh > 9 cm	Alive	Survivors
Alive, dbh > 9 cm	Dead	Mortality
Not measured	Alive, dbh < 9 cm	Regeneration
Not measured	Alive, dbh > 9 cm	Ingrowth
Not measured	Dead, dbh < 9 cm	Not considered

Table 2: Stand basal area distribution per quality class in 1983, 1999, and 2003

	All plots			Plots 1 to 5 & 12			Plots 1 to 3		
	AGS	UGS	Total	AGS	UGS	Total	AGS	UGS	Total
1983 before cut	n/a	n/a	28.8	n/a	n/a	29.1	n/a	n/a	29.3
1983 after cut	3.3	15.7	18.8	3.4	15.4	18.6	3.2	14.6	17.8
1999	10.5	11.0	21.5	9.4	11.2	20.6	10.8	9.9	20.7
2003	n/a	n/a	n/a	8.6	13.2	21.9	13.3	11.5	24.8

Figure 4: Evolution of stand basal area distribution per quality class through time



Stand annual BA growth (m²/ha/yr) was calculated for two observation periods (1983-1999 and 1983-2003) using the available data. As stated in Erdman and Oberg (1973), the following terms were used in growth analyses:

- **Survivor growth:** growth in BA of merchantable trees alive at both ends of the observation period;
- **Ingrowth:** BA of the trees that attained a merchantable size during the observation period;
- **Mortality:** BA of the merchantable trees that died during the observation period.

Living BA growth was the sum of survivor growth in BA + ingrowth BA. Results are presented on an annual basis in table 3. Since there were no control plots in the harvested area, it was not possible to evaluate the effect of the harvest on stand growth.

Section 1: Stand Growth Response

Results

From 1983 to 1999 (16 year period), stand total growth in BA averaged 0.16 m²/ha/yr: 0.07 m²/ha/yr from survivor and 0.09 m²/ha/yr from ingrowth (table 3). **Mortality rate averaged 0.19 m²/ha/yr. Among the stems that died during this period, approximately 15% were trees with major damaged to the bole.** The major damage definition and indicators used in this study were those defined in OMNR (1998).

Table 3: 16 year stand growth in basal area (all plots)

BA (m ² /ha)	Ingrowth	Survivor	Total
1983	0.00	18.93	18.93
1999	1.50	19.99	21.49
Δ 1983-1999	1.50	1.06	2.56
Growth (yr⁻¹)	0.09	0.07	0.16

Plots 1 to 5 and 12 were measured again in 2003 to evaluate the 20-year stand growth response in BA. For this subset of plots, stand total growth in BA averaged 0.15 m²/ha/yr: 0.10 m²/ha/yr from survivor and 0.05 m²/ha/yr from ingrowth (table 4). **Mortality rate averaged 0.09 m²/ha/yr. Nearly 14% of the trees that died 20 years after harvest had been impacted with major logging damage in 1983.**

Table 4: 20 year stand growth in basal area (plots 1 to 5 and 12)

BA (m ² /ha)	Ingrowth	Survivor	Total
1983	0.00	18.85	18.85
2003	1.06	20.81	21.87
Δ 1983-2003	1.06	1.96	3.02
Growth (yr⁻¹)	0.05	0.10	0.15

For both periods, **85% of mortality (in BA) consisted of low quality sawtimber left standing after the 1983 cut (table 5). All the AGS sawlogs (A1 and B1) that died were small or medium and none had been severely wounded (table 5).**

Table 5: Distribution of dead basal area among quality classes

	Sawlogs						Poles	
	AGS		UGS				AGS	UGS
	A1	B1	A	B	C	D		
1983-1999 (16 years)	3.8%	6.2%	0.0%	1.0%	27.0%	59.0%	0.0%	3.0%
All 12 plots	10.0%		87.0%				3.0%	
1983-2003 (20 years)	3.3%	8.5%	9.2%	0.0%	58.9%	18.7%	0.0%	1.4%
Plots 1 to 5 and 12	11.8%		86.8%				1.4%	

Section 2: Individual Tree Growth Response

Calculations

Average and relative annual growth rates in dbh and BA were calculated for all merchantable trees and for both observation periods. **Average growth rates** were calculated as the difference in size (dbh or BA) divided by the time between the two measurements. **Relative growth rates** were expressed as the percentage of size increase adjusted by the initial dimension (dbh or BA) of the tree. **Relative growth rates allowed for the exclusion of initial size effect in the evaluation of the reaction of a tree after cut.** Stems were grouped by species (Maple or Beech), size class (poles; small, medium, and large sawlogs), quality class (AGS or UGS) and damage class (little or no damage; severely damaged) using the criterion defined by the OMNR (1998). The SAS GLM program (SAS Institute Inc., 2000), with Tukey comparisons, was used to find differences between species and among classes for average and relative growth rates. Tests were considered significant if $p \leq 0.05$.

Results

For both observation periods, species and size class were the only single variables that significantly contributed to explain the variation found in dbh and BA growth rates (p was <0.0001 in almost all cases). Overall, Beech showed a greater growth response than Maple after cut. Therefore, further analyses were done separately for Maple and Beech. Poles also grew generally faster than sawlogs. Since tree size still explained most of the variation found in growth rates when analyzing separately for each species, size class was included as covariable in the models when testing for quality or damage class effect in order to avoid the inclusion of a hidden size effect in the analyses. Results are presented for Maple and Beech and for both periods in the next section.

American Beech

A total of eighty-seven (87) American Beech trees, among which only 19 showed severe logging injuries, were available for analysis. Because of this relatively small sample size, the presented results should be accepted as tentative.

Relative dbh and BA growth decreased with increasing tree size in American Beech. Poles showed significantly higher relative dbh and BA growth than small sawlogs for both periods ($p < 0.0001$). Relative BA growth was also higher in poles than in medium sawlogs from 1983-1999 ($0.002 < p < 0.02$). Average BA growth was higher in small sawlogs than in poles between 1983 and 1999 and higher in small than in medium sawlogs between 1983 and 2003 ($0.01 < p < 0.04$). No significant difference was found among size classes for average dbh growth rate ($0.05 < p < 0.24$). **No significant effect of quality class or damage class was found on average and relative dbh or BA growth 20 years after cut in American Beech ($0.29 < p < 0.74$).** From 1983 to 1999, however, AGS beech

trees showed a greater BA growth than UGS ones ($p=0.02$). During the same period, severely damaged trees had higher average and relative dbh increment as well as relative BA growth than undamaged ones ($0.009 < p < 0.02$). As mentioned earlier, these results must be interpreted with caution since only 19 beech trees had been severely damaged, among which 17 were poles. These damaged poles seem to be responsible for the significant difference detected in the test while damaged small trees show constantly lower growth than undamaged ones (see table 8 and figure 7). Average and relative dbh and BA growth rates are presented by size x quality class and size x damage class in tables 6 to 9 and figures 5 to 8.

Table 6: DBH and BA growth by size x quality class in Beech (16 year)

16 year all plots	cm/yr		%		m ² /ha/yr		%		N of trees	
	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS
Poles	0.43	0.31	38	35	0.0011*	0.0006*	45	39	2	30
S-Saw	0.36	0.27	22	15	0.0011*	0.0009*	32	22	1	5
M-Saw	n/a	0.08	n/a	3	n/a	0.0003	n/a	6	0	1

AGS: acceptable growing stock; UGS: unacceptable growing stock
 DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +
 * AGS BA growth was greater than UGS BA growth at $p < 0.05$, see figure 5.

Figure 5: 16 year DBH and BA growth by size x quality class in Beech

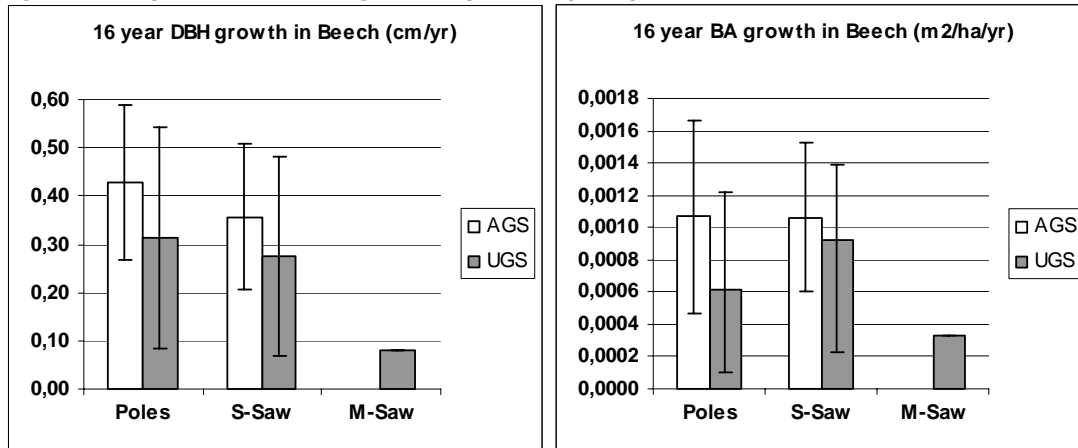


Table 7: DBH and BA growth by size x quality class in Beech (20 year)

20 year plots 1-5 & 12	cm/yr		%		m ² /ha/yr		%		N of trees	
	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS
Poles	0,25	0,33	28	45	0,0011	0,0014	66	120	2	30
S-Saw	0,29	0,27	23	19	0,0018	0,0019	52	43	1	5
M-Saw	n/a	0,04	n/a	2	n/a	0,0004	n/a	5	0	1

UD: trees with little or no damage; D: trees with severe logging damage.
 DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Figure 6: 20 year DBH and BA growth by size x quality class in Beech

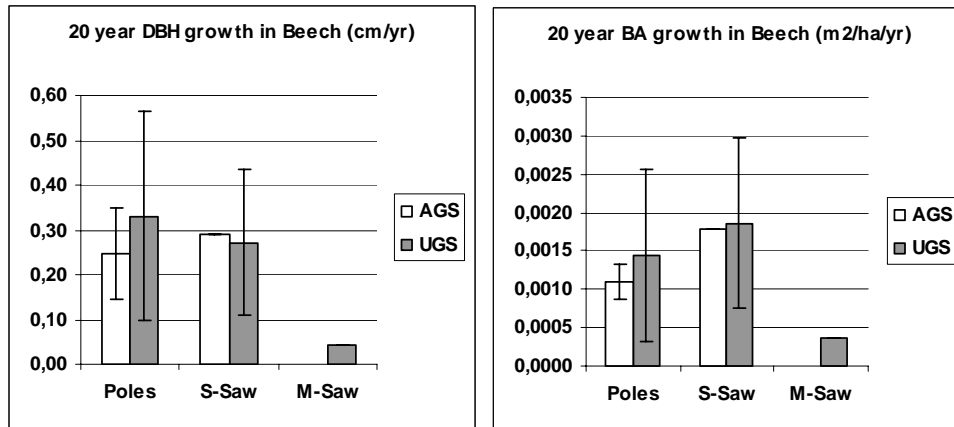


Table 8: DBH and BA growth by size x damage class in Beech (16 year)

16 year all plots	cm/yr		%		m ² /ha/yr		%		N of trees	
	UD	D	UD	D	UD	D	UD	D	UD	D
Poles	0.30*	0.45*	32*	49*	0.0006	0.0009	36*	54*	75	17
S-Saw	0.31*	0.19*	18*	10*	0.0010	0.0007	26*	15*	10	2
M-Saw	0.08	n/a	3	n/a	0.0003	n/a	6	n/a	1	0

UD: trees with little or no damage; D: trees with severe logging damage.

DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

* Damaged pole trees showed significantly greater growth rates than undamaged ones at p<0.05

Figure 7: 16 year DBH and BA growth by size x damage class in Beech

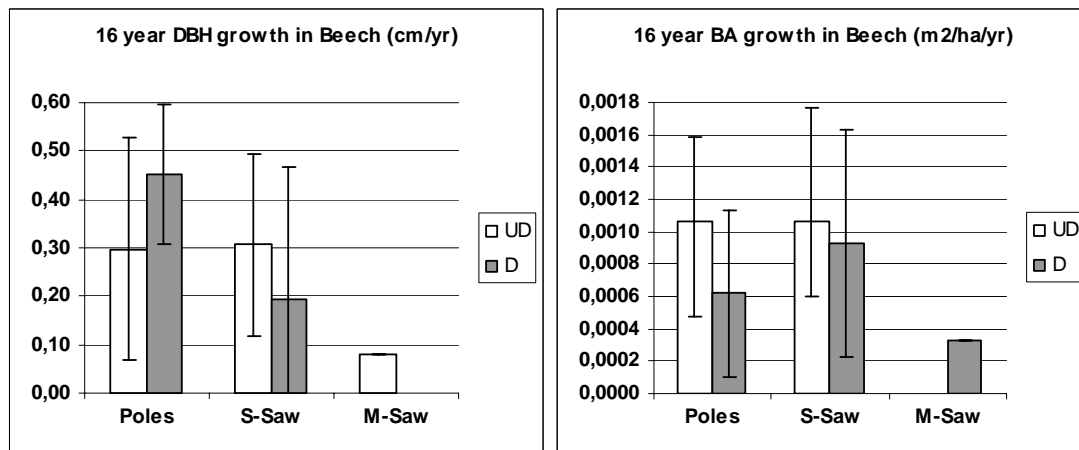


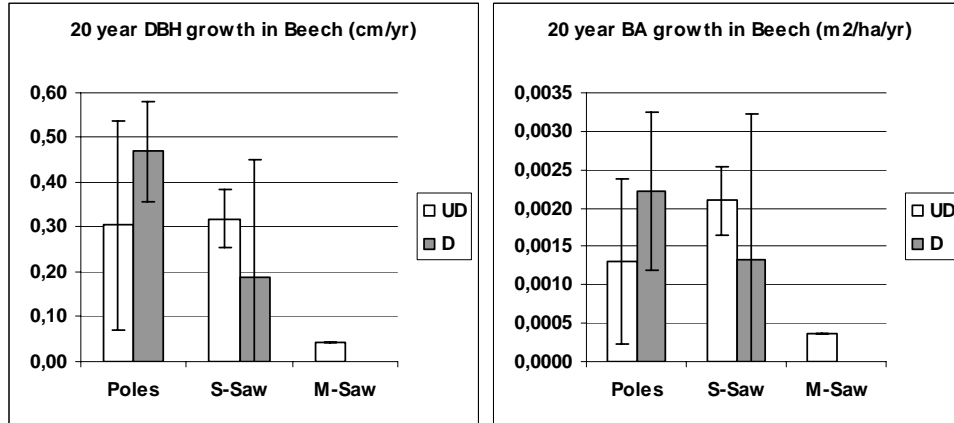
Table 9: DBH and BA growth by size x damage class in Beech (20 year)

20 year plots 1-5 & 12	cm/yr		%		m ² /ha/yr		%		N of trees	
	UD	D	UD	D	UD	D	UD	D	UD	D
Poles	0.30	0.47	41	58	0.0013	0.0022	111	151	28	4
S-Saw	0.32	0.19	24	12	0.0021	0.0013	53	28	4	2
M-Saw	0.04	n/a	2	n/a	0.0004	n/a	5	n/a	1	0

UD: trees with little or no damage; D: trees with severe logging damage.

DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Figure 8: 20 year DBH and BA growth by size x damage class in Beech



Sugar Maple

As it was the case for Beech, growth rates were mainly affected by tree size class in Maple. Growth has expressed on a relative basis decreased dramatically with increasing tree size. For both observation periods, poles had significantly higher relative dbh and BA growth rates than trees of all other size classes ($p < 0.0001$ in all cases). Between 1983 and 1999, large and medium sawlogs showed the highest average BA increment and grew significantly faster than poles ($p < 0.0001$). Medium sawlogs also had higher average BA growth rate than small sawlogs ($p \leq 0.0001$). Poles showed significantly higher dbh growth rate than small sawlogs for both observation periods ($p \leq 0.003$). **Overall, damage class had no significant effect on average and relative dbh and BA growth rates in Sugar Maple ($0.27 < p < 0.84$).** From 1983 to 1999, AGS maple trees showed a greater BA increment than UGS ones ($p = 0.04$). Average and relative dbh and BA growth rates are presented by size x quality class and size x damage class in tables 10 to 13 and figures 9-12.

Table 10: DBH and BA growth by size x quality class in Maple (16 year)

16 year all plots	cm/yr		%		m ² /ha/yr		%		N of trees	
	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS
Poles	0.16	0.14	13	15	0.0004*	0.0003*	20	21	26	107
S-Saw	0.16	0.12	8	6	0.0005*	0.0004*	14	11	14	37
M-Saw	0.13	0.13	5	5	0.0006*	0.0006*	9	9	3	23
L-Saw	0.12	0.09	4	3	0.0006*	0.0005*	7	5	1	7

AGS: acceptable growing stock; UGS: unacceptable growing stock
 DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +
 * AGS BA growth was greater than UGS BA growth at $p < 0.05$, see figure 9

Figure 9: 16 year DBH and BA growth by size x quality class in Maple

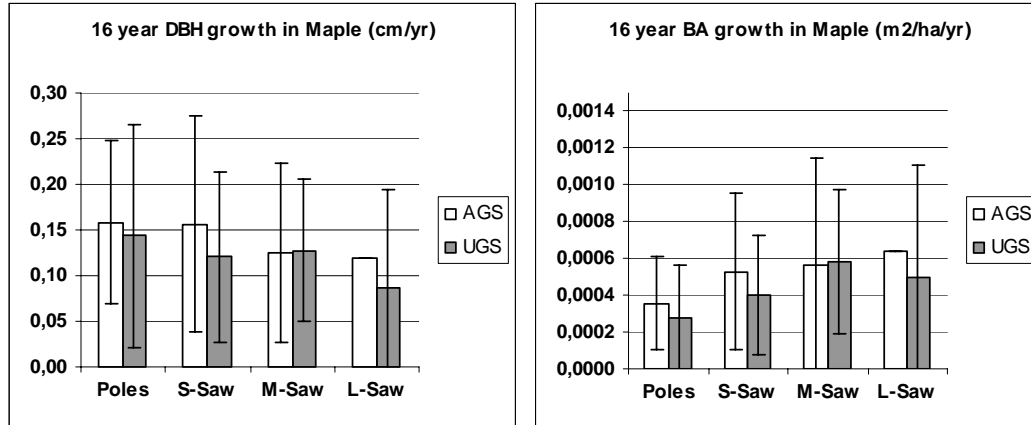


Table 11: DBH and BA growth by size x quality class in Maple (20 year)

20 year plots 1-5 & 12	cm/yr		%		m ² /ha/yr		%		N of trees	
	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS	AGS	UGS
Poles	0.26	0.31	26	40	0.0013	0.0015	61	106	26	107
S-Saw	0.16	0.15	17	20	0.0007	0.0006	39	48	14	37
M-Saw	0.13	0.12	9	8	0.0009	0.0008	19	17	3	23
L-Saw	0.19	0.11	9	5	0.0017	0.0010	20	11	1	7

AGS: acceptable growing stock; UGS: unacceptable growing stock

DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Figure 10: 20 year DBH and BA growth by size x quality class in Maple

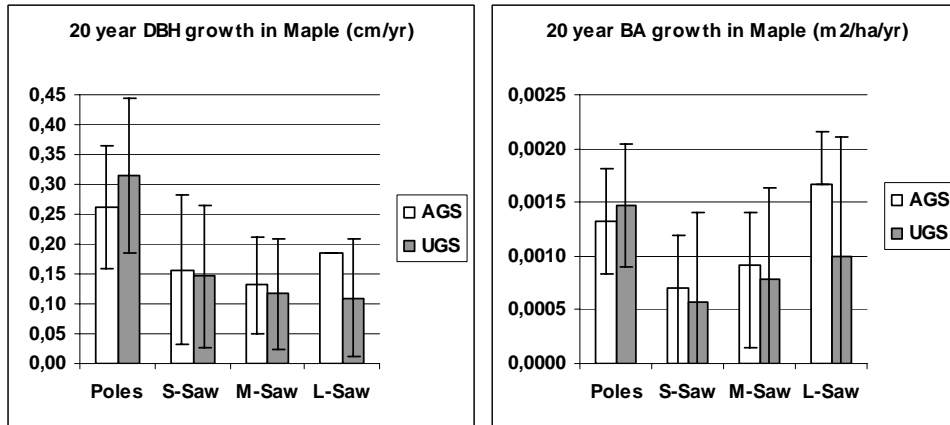


Table 12: DBH and BA growth by size x damage class in Maple (16 year)

16 year all plots	cm/yr		%		m ² /ha/yr		%		N of trees	
	UD	D	UD	D	UD	D	UD	D	UD	D
Poles	0.15	0.15	14	16	0.0003	0.0003	21	22	177	37
S-Saw	0.13	0.13	7	7	0.0004	0.0004	12	11	74	23
M-Saw	0.13	0.12	5	5	0.0006	0.0005	9	8	34	17
L-Saw	0.06	0.13	2	4	0.0003	0.0007	3	7	8	7

UD: trees with little or no damage; D: trees with severe logging damage.

DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Figure 11: 16 year DBH and BA growth by size x damage class in Maple

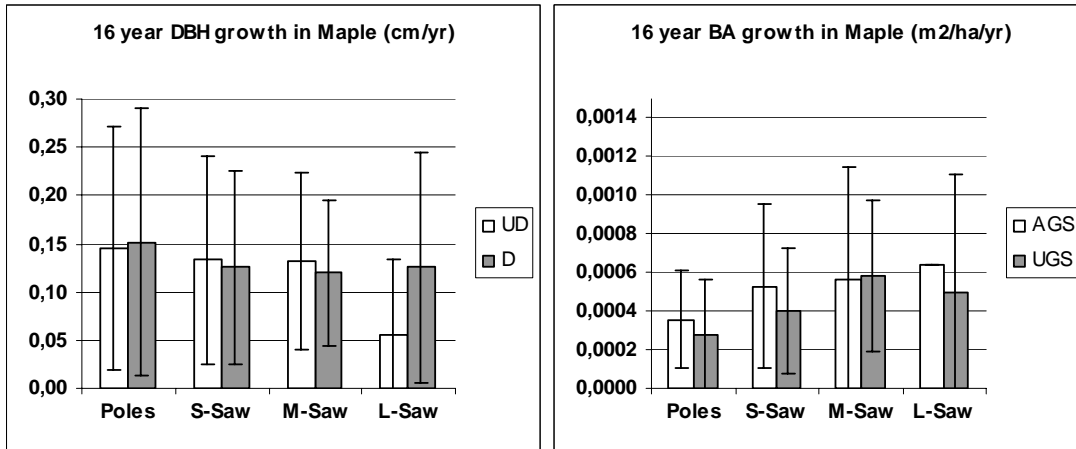


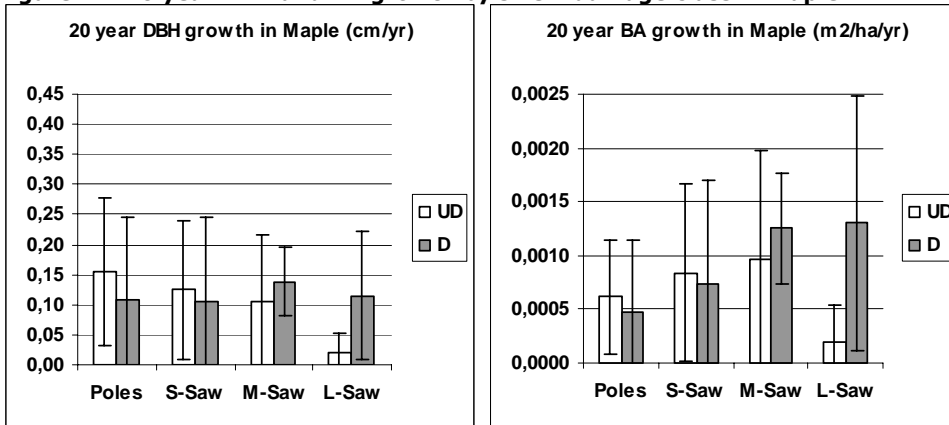
Table 13: DBH and BA growth by size x damage class in Maple (20 year)

20 year plots 1-5 & 12	cm/yr		%		m ² /ha/yr		%		N of trees	
	UD	D	UD	D	UD	D	UD	D	UD	D
Poles	0.15	0.11	21	14	0.0006	0.0005	48	32	116	17
S-Saw	0.12	0.11	9	7	0.0008	0.0007	18	15	40	11
M-Saw	0.11	0.14	5	7	0.0010	0.0013	11	14	16	10
L-Saw	0.02	0.11	1	4	0.0002	0.0013	2	9	3	5

UD: trees with little or no damage; D: trees with severe logging damage.

DBH (cm) : Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Figure 12: 20 year DBH and BA growth by size x damage class in Maple



Section 3: Volume, Products and Value Recovery

Harvest and sawmill operations

Plots 1, 2 and 3 were clear cut as part of the study in August 2003. Approximately 97% of stand BA (24.1 m²/ha of the 24.8²/ha available) including all stems larger than 20 cm dbh, was removed during the logging operations. Sixty-eight (68) Sugar Maple and twenty-seven (27) American Beech trees were harvested. Stems were bucked into sawlogs using Petro & Calvert (1976) grading criteria that allowed selecting the optimal bucking pattern. Logs were graded according to the Ontario scaling manual log grading system (OMNR, 2000). Sawlogs were brought to the Forintek sawmill and carefully sawn. Lumber products were graded according to the National Hardwood Lumber Association rules (NHLA, 2000). Boards were priced using average mill gate prices per grade. Lumber value was calculated as the summation of the nominal value given to each board generated from a log. Pulp logs were also scaled. Pulp value was assessed using a constant conversion factor (\$65.00 per anhydride metric ton of chip delivered to the mill). All prices used were obtained from studies conducted by Forintek in Central Ontario.

Calculations

Total merchantable volume (m³), decay volume (m³), lumber yield (m³, board foot), and products value (\$, \$/m³), were calculated for each harvested tree. The merchantable volume (net) of a tree consisted of the sum of the volume of each log generated from the individual tree (gross merchantable volume) minus the deduction for decay. Decay volume was estimated on the basis of visible defects on the log's extremities (Petro & Calvert, 1976). Decay content (%) was calculated as a proportion of gross volume. Lumber yield was expressed both in volume (m³) and board foot units (bf) and summed on a tree basis. Total product value consisted of lumber value and pulp value obtained from a single tree. Lumber yield and product value were also expressed by volume units (bf/m³; \$/m³). The SAS GLM program (SAS Institute Inc. 2000), with Tukey comparisons, was used to evaluate differences among species, tree size, stem quality and damage classes for the described dependent variables. Tests were considered significant if $p \leq 0.05$.

Results

Differences between Sugar Maple and American Beech

Sugar Maple had significantly higher merchantable volume, lumber yield (bf; bf/m³) and products value (\$; \$/m³) than American Beech ($p \leq 0.001$ in all cases). The proportion of grade 1 logs per tree was also greater in Sugar Maple ($p=0.002$), but decay content was not significantly affected by tree species ($p=0.51$). Average volume distribution, lumber yield and products value per tree are presented by species in table 14. Further analyses were done separately for each species. Again, tree size class was included in the models when testing for

quality or damage classes because size explained a large part of the variation observed in dependent variables.

American Beech

Merchantable volume, lumber yield and product value varied with tree size class in American Beech. However, the average dbh of harvested Beech was rather small so that poles and small sawlogs were the only sizes available in the dataset. Small sawlogs had significantly higher volume, lumber yield and product value than poles (p varied from 0.0171 to 0.0021, table 14). **No significant differences were found among quality classes ($0.14 \leq p \leq 0.74$) or damage classes ($0.18 \leq p \leq 0.94$) for any of the dependent variables tested.** Averages are presented by size x quality class in table 14.

Sugar Maple

Volume recovery, lumber yield and products value in Sugar Maple constantly increased with increasing tree size. Merchantable volume yield was closely related to size class with large sawlogs having the maximum volume ($p < 0.0001$). Product value and lumber yield were equivalent for medium and large sawlogs and in both case higher than for poles and small sawlogs ($p < 0.0001$). However, when expressed on a volume basis ($\$/m^3$), only medium and small sawlogs had significantly higher product value than pole trees ($p < 0.0001$). **Quality class had a significant effect on products value ($\$$ and $\$/m^3$) in Sugar Maple: stems with quality attributes (AGS trees) showed greater averages than low quality stems (UGS trees) in both cases ($p \leq 0.004$; table 15).** Other dependent variables remained unaffected by stem quality class ($0.08 \leq p \leq 0.60$) and **no significant effect was found for damage class overall ($0.07 \leq p \leq 0.96$).** Averages are presented by size x quality class in table 15.

Table 14: Average volume, log grade and products value per tree in Beech (plots 1 to 3)

AGS	Average net volume (m ³)						Lumber	Pulp	Products		
	Total	Gr1	Gr2	Lumber	Pulp	Cull	bf	val (\$)	val (\$)	val (\$)	val (\$/m ³)
Poles	0.20	0.00	0.07	0.07	0.13	0.00	13.4	4.45	5.09	9.54	47.69
S-Saw	0.54	0.09	0.12	0.21	0.33	0.00	57.5	21.67	9.92	31.60	58.39
UGS	Total	Gr1	Gr2	Lumber	Pulp	Cull	bf	val (\$)	val (\$)	val (\$)	val (\$/m ³)
Poles	0.19	0.00	0.08	0.08	0.11	0.00	13.5	5.57	4.29	9.85	51.91
S-Saw	0.49	0.00	0.11	0.11	0.37	0.01	39.2	14.40	11.41	25.81	52.57
M-Saw	0.64	0.00	0.00	0.00	0.64	0.00	54.0	20.20	16.38	36.58	57.19

AGS: acceptable growing stock; UGS: unacceptable growing stock
 DBH (cm): Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

Table 15: Average volume, log grade and products value per tree in Maple (plots 1 to 3)

AGS	Average net volume (m ³)						Lumber		Pulp	Products	
	Total	Gr1	Gr2	Lumber	Pulp	Cull	bf	val (\$)	val (\$)	val (\$)	val (\$/m ³)
Poles	0.20	0.00	0.06	0.06	0.14	0.00	23.3	10.73	4.72	12.23*	56.31*
S-Saw	0.53	0.11	0.22	0.33	0.20	0.00	75.9	58.06	6.44	64.50*	102.91*
M-Saw	1.13	0.63	0.18	0.81	0.32	0.00	210.8	224.82	9.00	233.81*	200.52*
UGS	Total	Gr1	Gr2	Lumber	Pulp	Cull	bf	val (\$)	val (\$)	val (\$)	val (\$/m ³)
Poles	0.24	0.00	0.08	0.08	0.16	0.00	31.1	16.97	6.03	15.45*	57.68*
S-Saw	0.52	0.09	0.21	0.31	0.22	0.00	80.6	63.07	8.27	61.38*	106.43*
M-Saw	1.00	0.50	0.36	0.86	0.14	0.00	185.0	146.92	8.91	155.83*	143.21*
L-Saw	1.43	0.84	0.10	0.94	0.46	0.03	188.9	145.02	20.95	165.97*	109.56*

AGS: acceptable growing stock; UGS: unacceptable growing stock

DBH (cm): Poles=9.1-25.0; S-Saw=25.1-37.0; M-Saw=37.1-49.0; L-Saw=49.1 and +

* AGS trees showed greater products value (\$ and \$/m³) than UGS trees.

Products recovery after clear cut

Total product value recovery after the clear cut of plots 1- 3 was \$15 773.44/ha. Sugar Maple yielded approximately 109 m³/ha; 68 m³/ha (62%) in lumber and 41 m³/ha (38%) in pulp products. Beech volume yield was about 22 m³/ha; 7 m³/ha (32%) in lumber and 15 m³/ha (68%) in pulp products. Overall, 45% of total harvested volume (47% of lumber volume and 44% of pulp volume) consisted of AGS trees. **Interestingly, harvested UGS trees yielded 8697 bf/ha.** Their value per lumber volume unit was however much lower than the value recovered from AGS trees: 160 \$/m³ of lumber for UGS versus 213 \$/m³ of lumber for AGS. Volume recovery, lumber yield and products value are presented by species and quality class on a per hectare basis in table 16.

Table 16: Volume, lumber grade and products value per hectare after clear cut (plots 1-3)

MAPLE	Average net volume (m ³ /ha)					Lumber	Pulp	Products			BA	m ² /ha
	Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³	
AGS	49.0	17.4	13.6	31.0	0.0	18.0	7725	7126	555	7682	157	6.12
UGS	60.0	20.9	15.8	36.7	0.5	22.9	7819	5990	941	6931	115	9.22
BEECH	Average net volume (m ³ /ha)					Lumber	Pulp	Products			BA	m ² /ha
Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³		
AGS	10.5	1.0	2.8	3.8	0.0	6.7	931	336	227	563	54	3.83
UGS	11.3	0.0	2.7	2.7	0.2	8.4	878	333	265	598	53	4.95
TOTAL	Average net volume (m ³ /ha)					Lumber	Pulp	Products			BA	m ² /ha
Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³		
AGS	59.5	18.4	16.4	34.8	0.0	24.7	8656	7462	782	8245	105	9.95
UGS	71.3	20.9	18.5	39.4	0.6	31.3	8697	6323	1206	7529	84	14.18
Both	130.8	39.2	35.0	74.2	0.6	56.0	17353	13785	1988	15773	95	24.13

Products recovery after selection cut

A tree marking exercise was done by the OMNR to reproduce a classical selection harvest of the same stand (plots 1 to 3). This cutting scenario removed 6.7 m²/ha out of 24.8 m²/ha, representing an approximate 27% removal of stand BA. **Product value recovery after selection cut would was \$4.079.48/ha**

overall. Sugar Maple yielded approximately 37 m³/ha: 23 m³/ha (62%) in lumber and 14 m³/ha (38%) in pulp products. American Beech volume yield was about 4 m³/ha: 1 m³/ha (33%) in lumber and 3 m³/ha (67%) in pulp products. Overall, 10% of the total harvested volume (10% of lumber volume and 12% of pulp volume) consisted of AGS trees. Volume recovery, lumber yield and product value are presented in table 17

Table 17: Volume, lumber grade and product value per hectare after selection cut (plots 1-3)

MAPLE	Average net volume (m ³ /ha)					Lumber	Pulp	Products	BA			
	Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³	m ² /ha
AGS	4.2	0.7	1.6	2.3	0.0	1.9	411	253	75	327	78	0.58
UGS	32.8	12.3	8.5	20.9	0.0	11.9	4192	3016	525	3542	108	4.74
BEECH	Average net volume (m ³ /ha)					Lumber	Pulp	Products	BA			
	Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³	m ² /ha
AGS	0.1	0.0	0.0	0.0	0.0	0.1	0	0.00	4	4	39	0.03
UGS	4.1	0.0	1.3	1.3	0.2	2.6	244	100	106	206	51	0.83
TOTAL	Average net volume (m ³ /ha)					Lumber	Pulp	Products	BA			
	Total	Gr1	Gr2	Lumber	Cull	Pulp	bf	\$	\$	\$	\$/m ³	m ² /ha
AGS	4.3	0.7	1.6	2.3	0.0	2.0	411	253	79	331	58	0.61
UGS	36.8	12.3	9.8	22.2	0.2	14.5	4436	3117	631	3748	79	5.58
Both	41.1	13.0	11.4	24.4	0.2	16.6	4847	3369	710	4079	69	6.19

AGS: acceptable growing stock; UGS: unacceptable growing stock

Discussion

Stand growth response after the 1983 single-tree selection harvest was rather low in the studied area. For both observation periods, ingrowth was good but the slow survivor growth and high mortality rates negatively affected stand BA reconstruction. **If logging damage were directly responsible for the death of the wounded trees that did not survive after cut, then a lost of 0.58 m²/ha (all plots) and 0.18 m²/ha (plots 1 to 5 and 12) could have been avoided 16 and 20 years after the harvest through the adoption of more careful logging practices. However, this would have led to only small changes in average mortality rates. Indeed, the most obvious explanation for the relatively high mortality observed is rather that many weak trees were left standing after the harvest to meet desired stand structural targets and wildlife needs.** Unfortunately, no detailed stand data is available to evaluate size and quality status structure prior to the 1983 harvest, leaving it is impossible to quantify the level of stand quality improvement achieved through the tree marking activity. The tree marking that was carried out was done following the state-of-the-art rules for single-tree selection silviculture in 1983 with the aim of improving stand quality following treatment. **While we are confident that a certain level of improvement in quality is actually achieved, many stands with a high grading history will require two or three cutting cycles to attain the target structure and quality level (OMNR, 1998) for optimum stand growth.**

In this study, tree species and size were the most important variables to explain tree growth response in dbh and BA following selection harvesting. Overall, a strong reaction was observed in poles while growth response remained lower in sawtimber classes. Majcen and Richard (1995), Majcen (1995, 1997) and Bédard and Majcen (2001, 2003) also observed stronger growth response after harvest in

dbh in stems smaller than 30 cm in dbh. **Nevertheless, since tree value is proportionally related with tree size, it is economically valuable to keep large trees standing as long as they are gaining volume without losing quality.**

The differences observed between Sugar Maple and American Beech individual trees growth reaction rates may be related to the fact that American Beech trees occupied lower dominance classes and younger age classes than the Sugar Maple trees. Young and suppressed trees of shade-tolerant species are more likely to benefit from gap creation after a selection cut.

The absence of quality or damage class effect on growth parameters in this study is in some ways surprising. However, it seems obvious that cull, weak and severely damaged trees were more likely to die when left standing after cut. In the present study, approximately 15% of the trees that died in the years following the cut had been severely impacted by logging operations. In addition, it is probable that both stand volume production and lumber yield will be negatively affected in the long term if these damaged and poor quality stems are to remain on the site. However, future tree marking activities and subsequent harvests (on a 20 year cutting cycle) will target many of these poorer quality and defective stems for removal resulting in a more healthy and vigorous stand.

Compared with American Beech, Sugar Maple yielded higher lumber volume, board foot units and product value. These differences may be explained by the following: 1) harvested Sugar Maple trees were larger than harvested Beech trees; 2) Sugar Maple lumber is much more valuable than American Beech lumber in the wood products market. For both species, volume, lumber and value recovery increased with increasing tree size. In Sugar Maple, product value peaked in the medium sawlog class for UGS trees. This is probably the consequence of degradation processes affecting large trees with low quality attributes. There were, unfortunately, insufficient data to assess the average products value of large AGS Maple trees. Nevertheless, since medium AGS trees show a much greater value than UGS trees of the same size, it appears highly valuable to grow large quality stems when managing Sugar Maple dominated stands. These results are illustrated in appendix A.

Conclusion

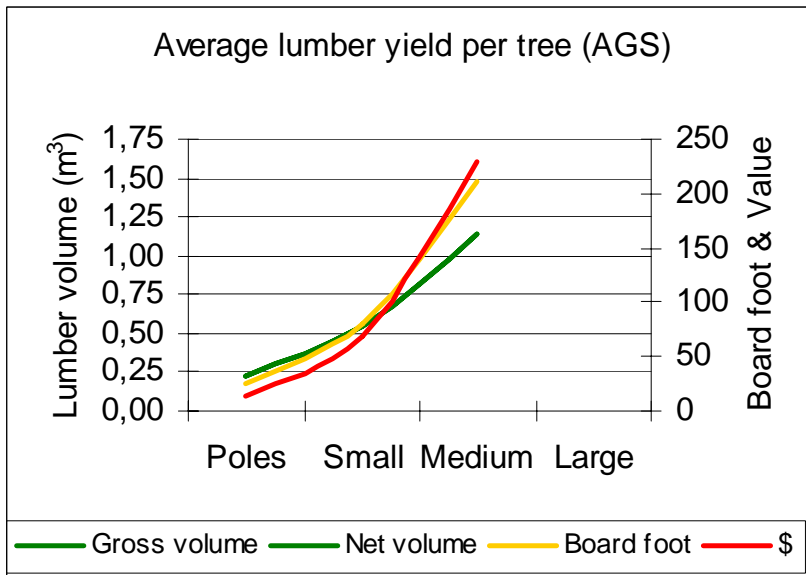
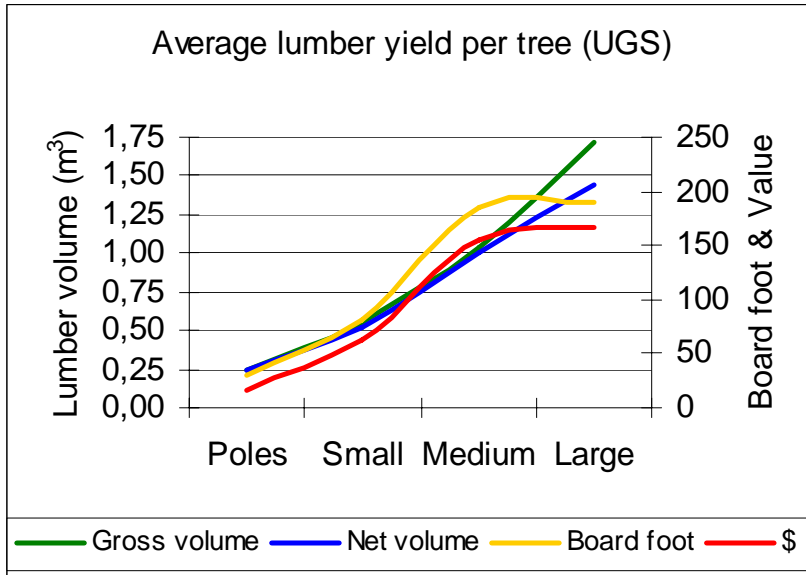
Analyses done in the present study revealed that stand growth rates after a single-tree selection harvest done in 1983 in the Marion Lake area was slightly lower than expected after the first cutting cycle. This can be related to at least two factors: 1) a high mortality rate after cut; 2) the slow growth rate observed among survivors. Within only one rotation, however, stand quality has largely improved: AGS trees proportion has more than doubled in twenty years. Since UGS trees are likely to show a slower growth rate and to be affected by decay processes with aging, stand productivity is also expected to improve over future cutting cycles. Finally, considering the fact that stem quality largely determines lumber products value in hardwoods, logging operations conducted without care can have serious negative consequences on both stand growth and product yield.

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Appendix A

Lumber volume, board foot yield and value recovery in Sugar Maple



AGS: acceptable growing stock; UGS: unacceptable growing stock