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Impacts of Partial Harvesting on Stand Dynamics and Tree Grades for Northern Hardwoods of the Acadian Forest Region

D. Edwin Swift, Isabelle Duchesne, Chhun-Huor Ung, Xiaodong Wang, and Roger Gagné

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Abstract

The objectives of commercial thinning and partial harvesting have traditionally been to improve and increase the amount of higher quality stems for sawlog and veneer products, reduce losses from mortality, and reduce harvest rotations for even-aged silvicultural systems. Literature on the impact of partial harvesting on stand dynamics, tree grade changes, fibre attributes, and potential forest products to promote uneven-aged stand structures and management is scarce for the northern hardwood forests of the Acadian Forest Region. A long-term selection harvest study established in west-central New Brunswick provides an opportunity to obtain such information under the Eastern Hardwood Research Initiative of FPInnovations and Natural Resources Canada, Canadian Wood Fibre Centre. Results from the study suggest that the treated stands benefited in terms of growth and improved quality, but stand restoration is a slow process in second-growth, uneven-aged stands on 20-year harvest cycles. Stand growth responses and tree grade changes for both the control and treated plots are within the values reported for northern hardwood stands and are influenced by a number of treatment and biological factors.

The results of 15 years of observation are discussed in the context of the major publications existing in the literature for stand dynamics, tree grade changes, and the occurrence of ingrowth. In summary, the greater the basal area removed, the greater the diameter response of individual residual trees in the thinned plots. The thinned stands have not recovered the basal area values that existed at the start of this study. Annual volume increment growth rates suggest that hardwood stands subjected to partial removals produced better growth response than was predicted at the start of the study. Stand restoration and stem quality improvement are slow processes that may not be achieved with a first harvest entry in second-growth northern hardwood stands that have repeatedly had the higher quality trees removed in the past. Changes in tree grades were observed to be very dynamic in these second-growth northern hardwood stands because of a number of factors such as initial stem quality, stem growth, mortality rates, harvest rates (both regulated and unregulated), species, and site quality. As expected, ingrowth occurred more frequently in the thinned stands than in the control stands. Except for one study site, which featured a more "mixedwood" characteristic, ingrowth did not exist as a diverse mixture of desired tree species but as a secondary canopy of American beech (*Fagus grandifolia* Ehrh.) and sugar maple (*Acer saccharum* Marsh.).

Résumé

L'éclaircie commerciale et la coupe partielle visent habituellement à améliorer et à augmenter la quantité des tiges de haute qualité pour la production de billes de sciage et de produits de placage ainsi qu'à réduire la mortalité des arbres et la révolution des peuplements en régime équienne. Peu d'études ont été publiées concernant les effets de la coupe partielle sur la dynamique des peuplements, la qualité des arbres, les attributs des fibres et les produits forestiers possibles pour favoriser l'aménagement inéquienne des forêts de feuillus nordiques de la région forestière acadienne. Une étude à long terme sur la coupe sélective dans le Centre Ouest du Nouveau-Brunswick offre une occasion d'obtenir ce genre de données, dans le cadre de l'Initiative sur les feuillus de l'Est de FPInnovations et du Centre canadien sur la fibre de bois de Ressources naturelles Canada. Les résultats de l'étude portent à croire que le traitement a augmenté la croissance et la qualité des arbres, mais le rétablissement des peuplements est un processus lent dans les peuplements inéquiennes de seconde venue soumis à des cycles de récolte de 20 ans. La croissance des peuplements et l'évolution de la qualité des arbres dans les parcelles témoins et les parcelles traitées montrent des valeurs analogues à celles signalées dans les autres études sur les peuplements de feuillus nordiques et sont le jeu d'un certain nombre de facteurs biologiques et de facteurs relatifs au traitement.

Nous examinons les résultats de 15 années d'observation à la lumière des principales études publiées sur la dynamique des peuplements, l'évolution de la qualité des arbres et le recrutement. En résumé, plus la surface terrière est réduite par une coupe d'éclaircie, plus le diamètre des arbres résiduels augmente. Les peuplements éclaircis n'ont toutefois pas atteint la surface terrière qu'ils avaient au début de l'étude. Les taux d'accroissement annuel du volume indiquent que les peuplements de feuillus soumis à des coupes partielles ont présenté une meilleure croissance que prévu au début de l'étude. Le rétablissement du peuplement et l'amélioration de la qualité des tiges se font lentement, et ne s'obtiennent pas nécessairement après une première coupe dans les peuplements de feuillus nordiques de seconde venue où les arbres de plus grande qualité ont été récoltés à plusieurs reprises par le passé. L'évolution observée de la qualité des arbres est très variable dans ces peuplements en raison de plusieurs facteurs comme la qualité initiale des tiges, la croissance des tiges, le taux de mortalité, le taux de récolte (réglementé ou non), l'essence et la qualité du site. Comme prévu, le recrutement est plus fréquent dans les peuplements éclaircis que dans les peuplements témoins. Dans tous nos sites sauf un, où le peuplement est plus mixte, le recrutement ne consiste pas en un mélange diversifié d'essences désirées, mais en un dense couvert secondaire de hêtres à grandes feuilles (*Fagus grandifolia* Ehrh.) et d'érables à sucre (*Acer saccharum* Marsh.).

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Introduction

Northern hardwoods are a major forest type in eastern Canada (Farr 2003). These stands contain ecologically and economically important tree species and associations in the region (Mulliens and McKnight 1981, Farr 2003). The hardwood lumber industry in eastern Canada is currently in a vulnerable position because of reduced demand from the American market as well as the transfer of manufacturing facilities for furniture and other secondary products to other regions (Ouellet and Fournier 2009; F. Fournier, personal communication, 21 September 2010, Fredericton, New Brunswick; D. Toole, personal communication, 24–25 March 2011, Truro, Nova Scotia). The allowable annual cut (AAC) is being adjusted in some jurisdictions to account for the changes occurring in the hardwood resource and industry (J. Landry, F. Fournier, and D.E. Swift, personal communication, 22 February 2012). To address the present concerns and improve the competitiveness of the hardwood industry in eastern Canada, a hardwood research initiative was undertaken in 2008 by Natural Resources Canada, Canadian Wood Fibre Centre and FPInnovations along the value chain of hardwood products. This hardwood research initiative was developed in partnership with resource managers and industrial forestry organizations from New Brunswick, Nova Scotia, Ontario, and Quebec. Participation by university researchers was also included in the program. Funding was provided by Natural Resources Canada's Transformative Technologies Program. The Hardwood Research Initiative comprises 18 projects that range across market analysis, user need analysis, manufacturing, harvesting, and the impact of silviculture on the hardwood resource (J. Landry, F. Fournier, and D.E. Swift, personal communication, 22 February 2012). This report provides preliminary results of one of the three projects that concern knowledge of economic and silvicultural opportunities.

Tree quality of hardwoods is an important factor that is used in eastern Canada to influence decisions made by foresters for silvicultural prescriptions at the stand and landscape levels. Potential grades for present and future products are based on external stem features or attributes. Despite the usefulness of projected tree grades, there are a limited number of studies in eastern Canada that document the accuracy of tree grade projections through time in terms of growth response, reduction of losses from mortality, improved stem quality, and value for future forest products (Guillemette et al. 2008, Fortin et al. 2009; S. Bédard and A. Stinson, personal communication, 19–21 October 2010, Hunstville, Ontario). A former partial harvest study in west-central New Brunswick provided an opportunity to examine the aforementioned factors concerning tree grade projections. Project 17 of the Hardwood Research Initiative examines the impact of partial harvesting on stand dynamics, accuracy of tree grade projections, wood fibre attributes, and product recovery for northern hardwoods of the Acadian Forest Region. The objectives of Project 17 are listed on the next page.

Objectives

1. Verify current tree grade projections and products used in New Brunswick to classify potential forest products and mortality risk.
2. Determine the accuracy of tree grade projections for hardwood species of the Acadian Forest Region.
3. Determine whether the accuracy of tree grade projections for hardwood species in the Acadian Forest Region is influenced or affected by partial harvesting, initial tree size (diameter at breast height (dbh) and crown), initial crown position, and site conditions.
4. Determine the different levels of mortality risk based on tree grade projections by specific species mortality models for individual trees of the Acadian Forest Region.
5. Examine the impacts and relationships of silvicultural practices (density regulation through partial harvesting) on tree growth, stand dynamics, external quality, fibre attributes, and value in northern hardwood forests of the Acadian Forest Region.
6. Examine the impacts and relationships of silvicultural practices (density regulation through partial harvesting) on wood color of sugar maple (*Acer saccharum* Marsh.), and yellow birch (*Betula alleghaniensis* Britton) in northern hardwood forests of the Acadian Forest Region.
7. Devise and validate statistical equations predicting standing tree value in relation to variables selected at the tree and stand levels for their cost effectiveness and wood properties derived from soundings taken with acoustic sensors on standing trees.
8. Incorporate information obtained in this study to regional growth and yield models, such as Staman (Norfolk 2004), used by foresters in the Maritime provinces of Canada.
9. Incorporate information obtained in this study to regional inventory procedures used by foresters in eastern Canada.

This report provides the preliminary results for stand dynamics, tree grade changes, and the occurrence of ingrowth (Objective 5).



Figure 1. Location of the six study sites in New Brunswick; 1 = Grand John #2, 2 = McLean's Brook, 3 = Grand John #1, 4 = Dunbar #1, 5 = Dunbar #2, 6 = Wiggins's Corner.

Materials and Methods

Study Site Descriptions

The six study sites were obtained from an earlier northern hardwood study on Crown License 8 of AV Nackawic Inc. in west-central New Brunswick (Fig. 1). The purpose of the original study was to examine the growth response and stand dynamics of northern hardwood stands to an uneven-aged silvicultural prescription. It is the oldest partial harvest study in northern hardwood stands in New Brunswick. The study sites used in this research project are located in the northern hardwoods of the Acadian Forest Region (Rowe 1972). These stands consisted primarily of various amounts sugar maple, yellow birch, red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) with minor associations of white ash (*Fraxinus americana* L.), striped maple (*Acer pensylvanicum* L.), ironwood (*Ostrya virginiana* (Mill.) K. Koch), trembling aspen (*Populus tremuloides* Michx.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), balsam fir (*Abies balsamea* (L.) Mill.), and red spruce (*Picea rubens* Sarg.) (Table 1). Beech scale disease (*Nectria coccinea* (Pers.: FR.) Fr. var. *faginata* Lohman, Watson, and Ayers) has had a major influence on the condition and occurrence of American beech in the study area (Boyce 1961, Myren 1994). The initial “killing front” of the disease occurred long ago, but regional forest pest monitoring did not report the disease as a major pest problem at the time of study establishment in 1993 (Magasi and Hurley 1994).

Past harvesting and agricultural practices have greatly influenced the existing forest stand structures in the region (Zelazny 2007). Examination of increment cores taken from trees in the study stands in 2010 revealed that these second-growth hardwood stands are the result of repeated removal of the better quality stems by partial harvesting practices (Table 2). Selection harvesting was the harvest method traditionally used in the Maritimes for sawlog and custom log production (Lees 1978). The stand ages range from 40 to 160 years for all the study sites, providing seedling establishment dates between 1850 to 1970. The forest stand structures of the study sites are very typical of the hardwood resource in the New Brunswick (McDonald 1999) and Quebec (Roberge 1988b, Guillemette et al. 2012). Stand development of hardwoods of the Appalachian Region have similar harvesting histories (Miller et al. 2003, 2008).

Table 1 Percent occurrence of tree species in 1993 weighted by basal area before harvesting for each study site and treatment

Study Site	Tree Species									
	Sugar Maple		Yellow Birch		Red Maple		American Beech		Other Species*	
	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned	Control	Thinned
Grand John #2	61	72	31	1	1	11	1	1	8	15
McLean's Brook	49	44	17	7	0	0	34	49	0	0
Grand John #1	63	60	9	1	0	0	25	34	2	5
Dunbar #1	–	0	–	49	–	37	–	4	–	20
Dunbar #2	51	49	24	10	14	24	7	15	4	2
Wiggin's Corner	45	19	7	7	13	38	27	23	7	13

* white ash, striped maple, ironwood, trembling aspen, eastern hemlock, balsam fir, and red spruce

Table 2 Age information at stump height by study site and treatment in 2010

Study Site	Treatment	Age (years)	Date	Comments
Grand John #2	Control	40–160 (90)	1850–1970 (1920)	
	Thinned	50–110 (90)	1900–1960 (1920)	
McLean's Brook	Control	40–100	1920–1970	
	Thinned	50–80	1930–1960	small sample
Grand John #1	Control	40–100	1910–1970	
	Thinned	40–90	1920–1970	
Dunbar #1	Control	NA	NA	not established
	Thinned	–	–	not sampled
Dunbar #2	Control	40–140 (110)	1870–1970 (1900)	
	Thinned	50–110	1870–1960	small sample
Wiggin's Corner	Control	70–150 (120)	1850–1940 (1890)	
	Thinned	50–150 (110)	1860–1960 (1900)	

Table 3 Different site characteristics among the three ecodistricts of the study sites (from Zelazny 2007)

Study Site	Ecodistrict	Area (ha)	Average elevation above sea level (m)	Average May–September precipitation (mm)	Average annual degree days above 5° C
Grand John #2 McLean's Brook Grand John #1	Buttermilk	215,338	245	450–500	1650–1750
Dunbar #1 Dunbar #2	Cardigan	86,707	150	400–450	1550–1700
Wiggin's Corner	Nackawic	143,646	185	425–450	1650–1700

A more recent forest classification system places these study sites in the Central Uplands Ecoregion (Zelazny 2007). This ecoregion is the largest in New Brunswick and is characterized by its diversity of landscape features. The Central Uplands Ecoregion features a continental climate that is sheltered from maritime influences and receives lower precipitation amounts than surrounding ecoregions. Summers are warmer, and winters are cooler than in areas closer to the Northumberland and Bay of Fundy coasts. Because of cool nights caused by frost pockets, the northern hardwood forests of the ecoregion tend to exist on the upper slopes of ridges and hills. The six study sites exist in three of 12 ecodistricts in this ecoregion (Table 3). Ecodistricts are characterized by climatic differences such as average May–September precipitation and average annual degree days above 5°C. The forest soils of the Buttermilk and Cardigan ecodistricts are considered less fertile than those of the Nackawic ecodistrict.

Treatments

A harvest intervention or cutting cycle of 20 years was chosen for the uneven-aged silvicultural prescription. The tree removal priority criteria were as follows:

- mature to over-mature spruce (*Picea* spp.) and balsam fir
- trees exhibiting imminent mortality
- low quality American beech
- all trees with >40 dbh
- all trees of low external stem quality of <40 cm dbh

One of the objectives of the partial harvests was to achieve a post-harvest residual basal area of 16–18 m²/ha. The harvest operation consisted of manual felling with chainsaws and removal of felled trees by cable skidders. Harvesting of all trees was conducted between September and December of 1993 on all study sites.

Experimental Design

In 1993, two 40 x 40 m (1600 m²) permanent sample plots (PSPs) were established as overstorey base plots in each stand or study site. One PSP was established in a portion of the stand that did not receive the harvesting prescription, hereafter referred to as the control plot. The other PSP was established in the portion of the stand that received the harvesting prescription, hereafter referred to as the thinned plot. The establishment of both control and thinned plots in the same stand or study site produced a “paired plot” experimental design. Because of time constraints in 1993, a control plot was not established at the Dunbar #1 study site (Table 2). In subsequent years, the thinned area at the Dunbar #1 study site received unauthorized partial harvesting of the better quality trees and the area was abandoned as a study location. Because of these establishment inconsistencies and unauthorized harvesting activities, the Dunbar #1 study site was excluded from further examination and analysis in this report. Within each PSP, four 20 x 20 m sub-plots or quadrats were established to facilitate overstorey tree location and measurement. Quadrats were numbered 1 to 4, starting in the southwest corner of the PSP. To minimize edge effects due to future roads and stand treatments, a 20- to 40-m buffer strip was established around each PSP.

Tree Measurements

Measurements of the overstorey trees were carried out in 1993 (immediately after treatment), in 1998 (5 years after treatment), and in 2008 (15 years after treatment). For a variety of reasons, overstorey tree measurements were not taken for all of the PSPs on these dates. As previously stated, a control plot was never established at the Dunbar #1 study site. Some time after the 1998 measurement, unauthorized harvesting occurred in the thinned area of the Dunbar #1 study site to the extent that the tree measurements in 2008 were not possible. In 2008, the thinned plot at the McLean’s Brook study site was clearcut before any tree measurements were recorded. Tree measurements were not recorded in 1998 for the Wiggin’s Corner study site. Such discrepancies or shortcomings in sampling often occur with long-term research studies and can be adequately addressed with appropriate analysis techniques.

In 1993, all trees >9.9 cm were classified as overstorey trees and were assigned a number and mapped for location; tree measurements were recorded before the harvest operation. The overstorey trees

were numbered consecutively, starting in the left front corner of the first sub-plot or quadrat. Overstorey tree mapping was accomplished by recording the distance and bearing of each tree from the corners at the bottom or front (A and B line) of each sub-plot. Trees that measured <9.9 cm dbh in 1993 but subsequently reached that measurement in 1998 or 2008 are considered ingrowth. The following tree measurements were recorded in 1993, 1998, and 2008: (1) species, (2) stem diameter (dbh, cm) at 1.30 m, (3) total tree height (m), (4) height to live crown (m), (5) crown width (cm), (6) crown class (after Nyland 1996), (7) crown shape, and (8) external stem quality based on the system used by the New Brunswick Department of Natural Resources (Appendix I). Crown width recordings consisted of one measurement taken in the same direction as the tree mapping procedures or A and B line. After the harvesting operation in 1993, stem damage to the residual trees was recorded. The external tree grade system of Monger (2007) was also included in the 2008 measurements.

In 2009, trees in the buffer areas surrounding the PSPs at the Dunbar and McLean's Brook study sites were sampled for the destructive analysis phase of this project (Project 17) and Project 16 (Duchesne et al. 2012).

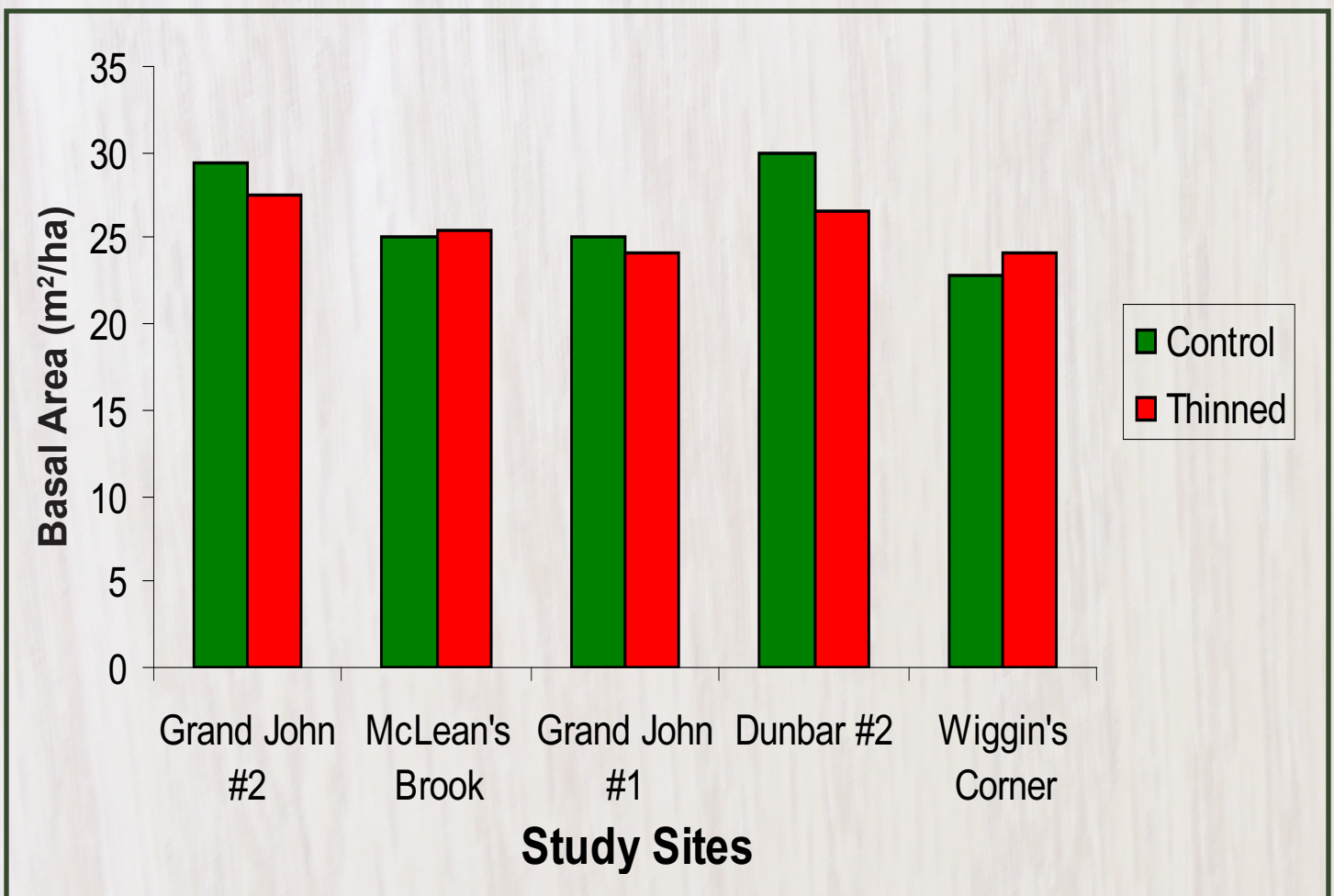


Figure 2. Basal area (m²/ha) in 1993 before thinning by treatment and study site.

Results

Stand Dynamics

Aside from differences in the frequency and occurrence of tree species (Table 1), basal area (m^2/ha) also varied among plots and study sites (Fig. 2). Pre-treatment basal area ranged from 22.9 to $29.3 \text{ m}^2/\text{ha}$. The harvesting intensity on the thinned plots also varied among study sites: 23–56% (Fig. 3). Although not all study sites achieved the targeted residual basal area of $16\text{--}18 \text{ m}^2/\text{ha}$, such a range of harvest intensities is preferred for this type of research study. The average stand diameter response of the residual trees exhibited the expected trend of the greater the removal, the greater the growth response, with thinned plots increasing more in stem growth than control plots (Fig. 4). The initial decrease in diameter growth for the thinned plots was caused by the removal of $>40 \text{ cm dbh}$ trees. Stand basal area growth on the control plots exhibited variable responses to the thinning intensities (Fig. 5). In some plots (McLean's Brook, Grand John #1 and #2), stand basal area showed the expected relationship of increased growth over time, whereas in other plots, stand basal area remained constant (Wiggin's Corner) or decreased (Dunbar #2). All the thinned plots exhibited positive basal area growth following treatment. However, none of the thinned plots have recovered to the basal area levels before thinning 15 years ago.

The annual volume increment for the first 5 years (Fig. 6) is very variable and can be classified into three distinct groups: negative response (three plots), marginal response (three plots), and very positive response (two plots). The high positive growth response for annual volume increment for this period occurred on the Grand John #1 study site, with the thinned plot having a higher annual volume increment growth than the control plot. The average volume increment for the control plots was $0.2 \text{ m}^3/\text{ha}/\text{yr}$ whereas the thinned plots had twice the average volume increment, $0.4 \text{ m}^3/\text{ha}/\text{yr}$.

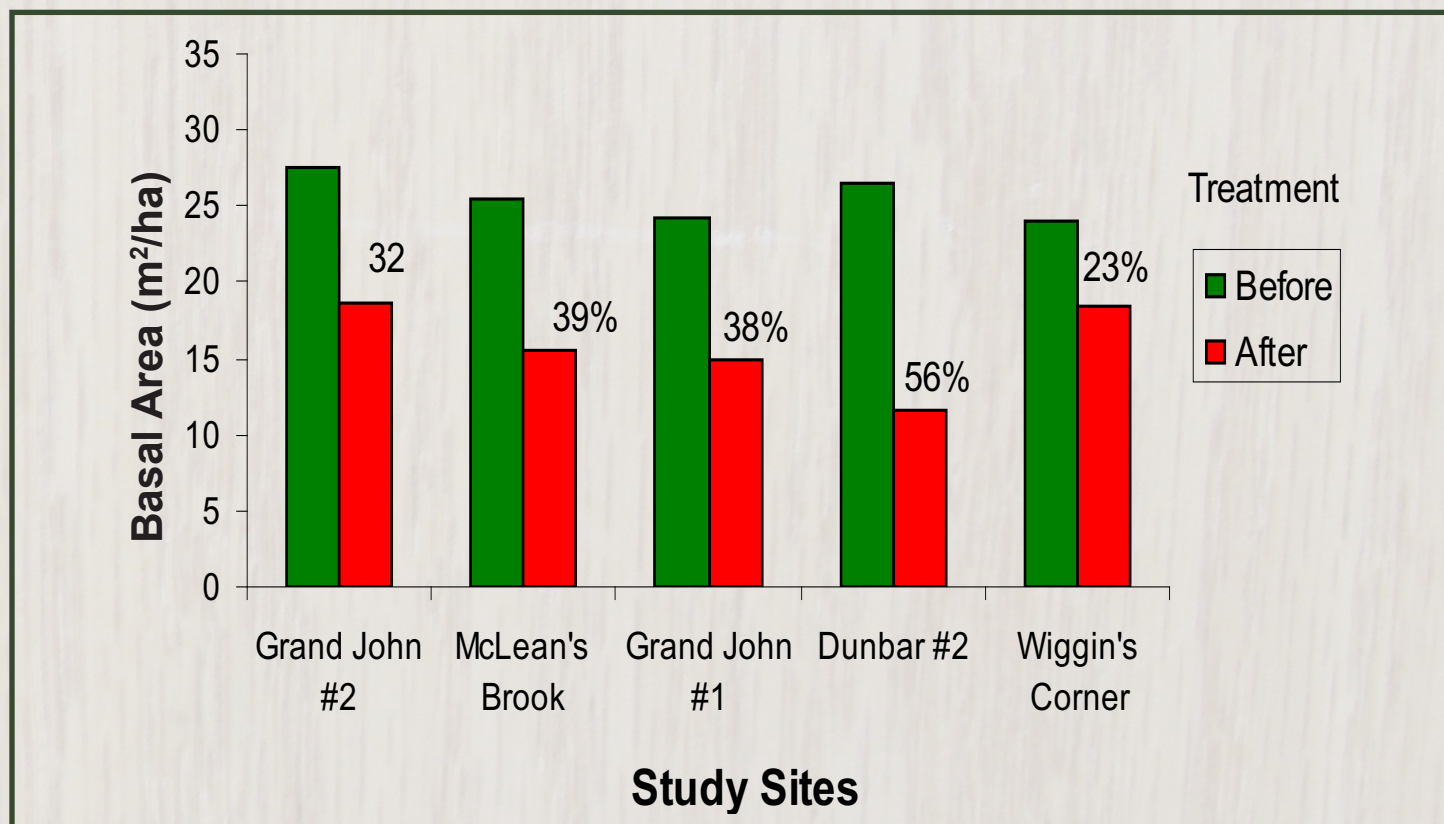


Figure 3 Basal area removal (m^2/ha) in 1993 by treatment and study site.

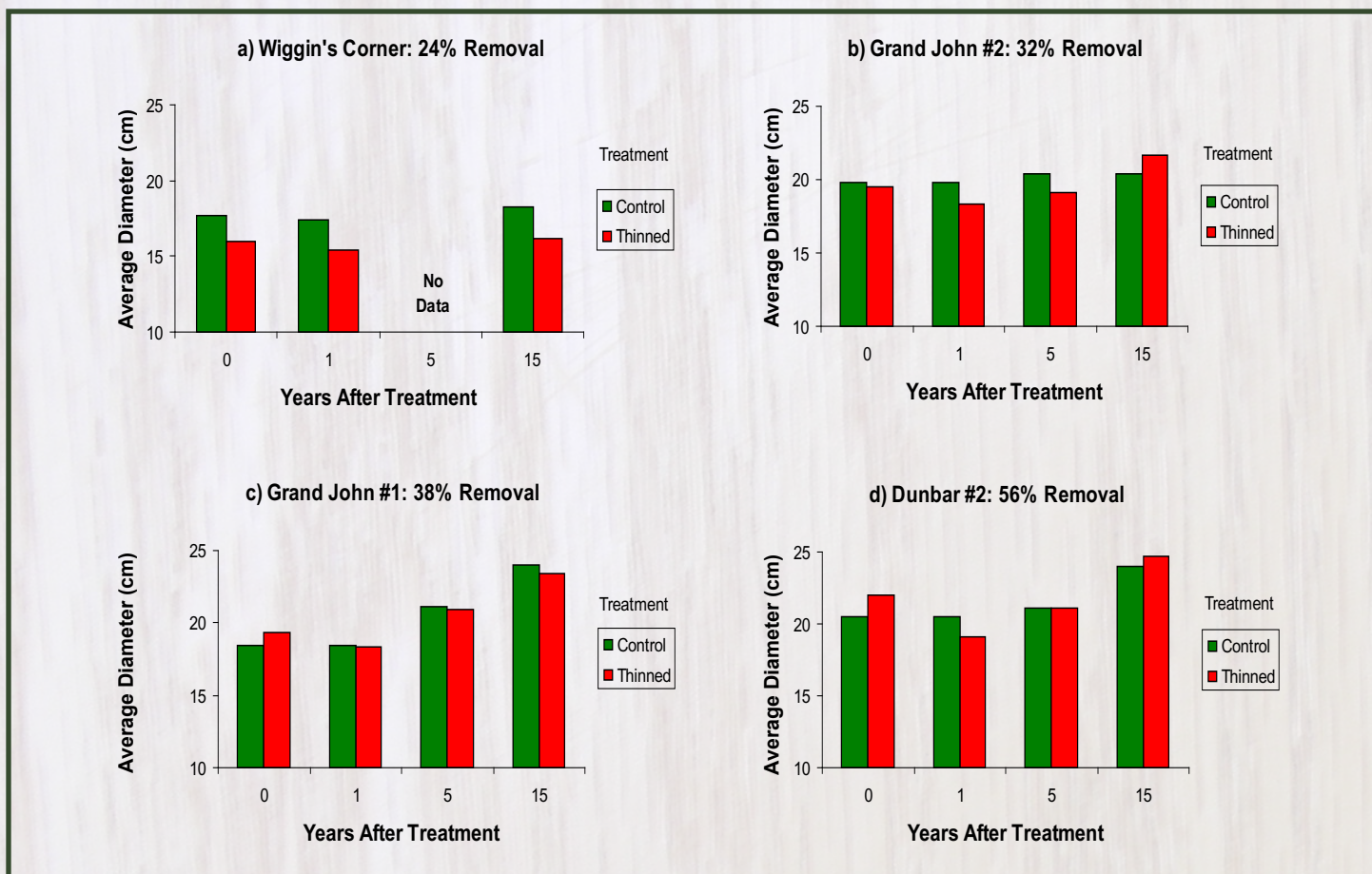


Figure 4. Average diameter (cm) growth response of the crop trees for four of the study sites.

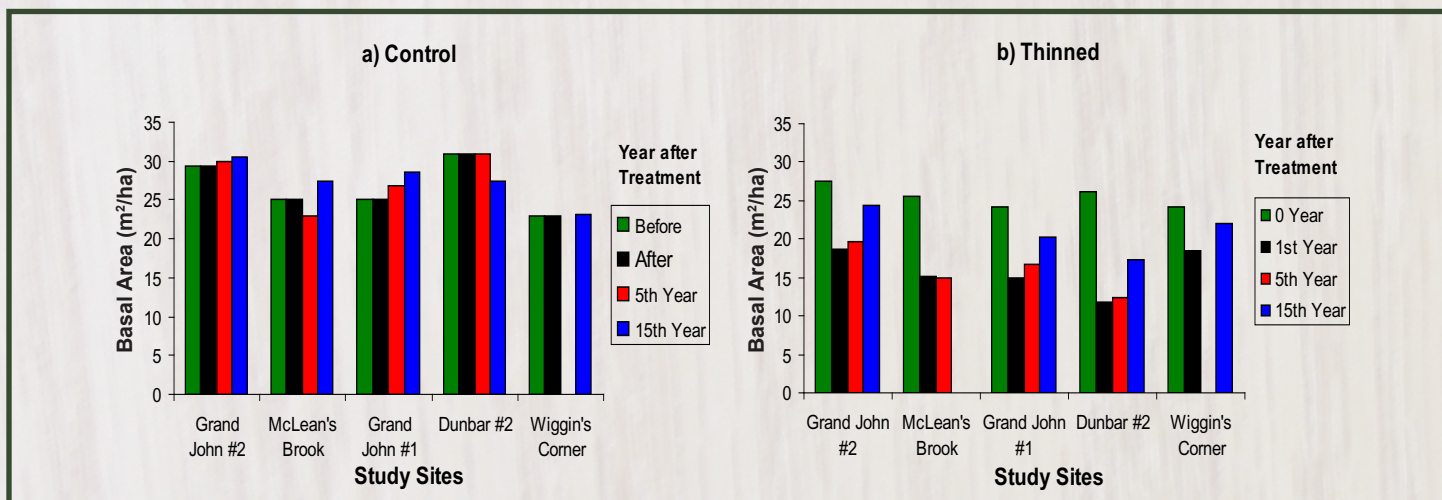


Figure 5. Basal area (m²/ha) response by treatment and study site.

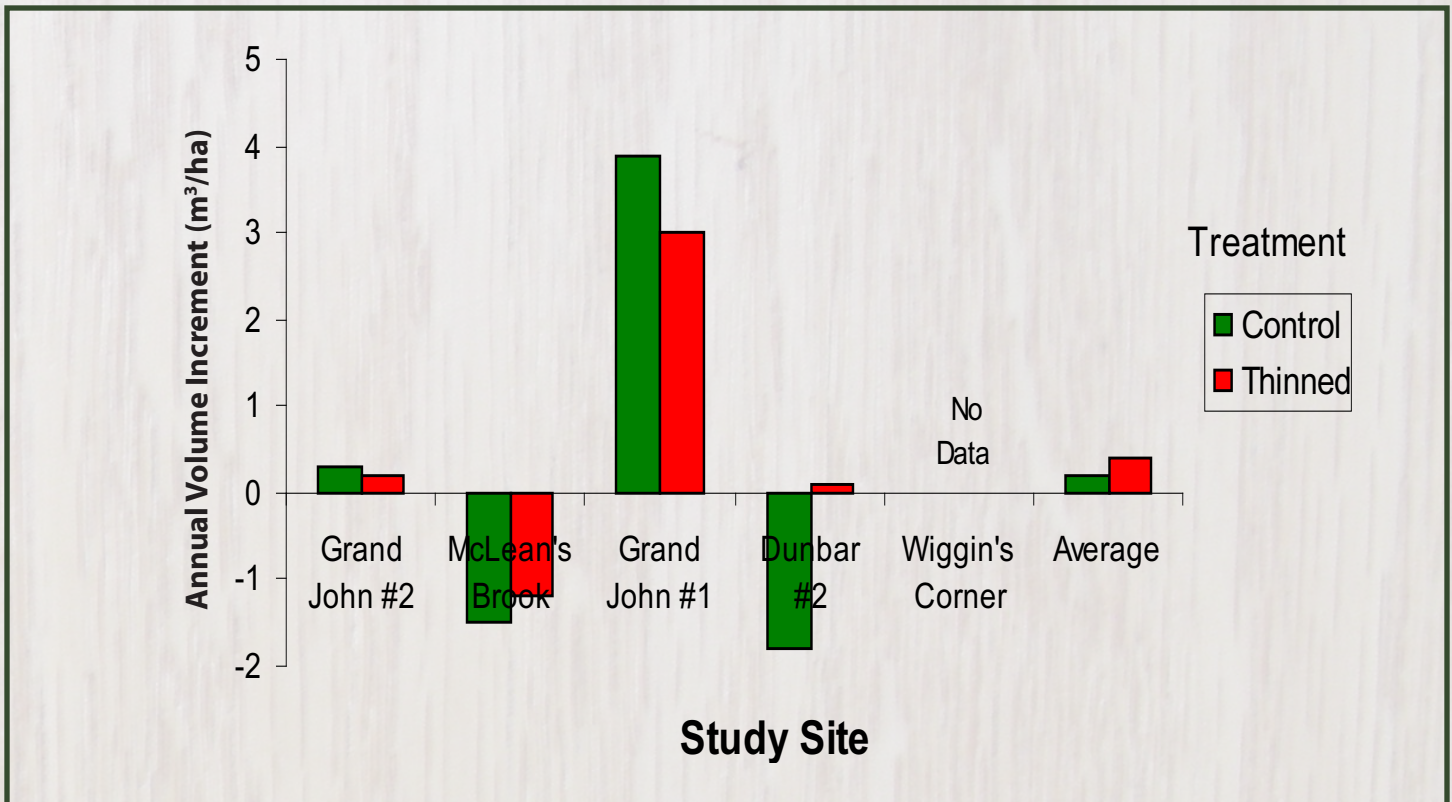


Figure 6. Average annual volume increment (m^3/ha) for the first 5 years by treatment and study site.

The annual volume increment ($\text{m}^3/\text{ha}/\text{yr}$) for the 15-year period exhibited positive and variable growth responses in all plots except one (Fig. 7). The control plot at the Dunbar #2 study site displayed negative annual volume increment growth due to mortality of some large trees in the plot. The average annual volume increment for the control plots was $2.3 \text{ m}^3/\text{ha}/\text{yr}$. The thinned plots showed a slightly higher average annual volume increment of $2.8 \text{ m}^3/\text{ha}/\text{yr}$.

When the data for the last 10 years (years 5–15) were examined, which allowed for an adjustment period from the partial harvest, the residual trees from all study sites, except for one control plot (Dunbar #2), exhibited positive and often favorable volume increment growth (Fig. 8). It was predicted that northern hardwood stands in New Brunswick would produce an annual volume increment growth of $2.4 \text{ m}^3/\text{ha}/\text{yr}$. The average annual volume increment growth for the control plots is below the predicted value at $1.3 \text{ m}^3/\text{ha}/\text{yr}$. The thinned plots on average exceeded the predicted amount for annual volume increment growth at $4.0 \text{ m}^3/\text{ha}/\text{yr}$.

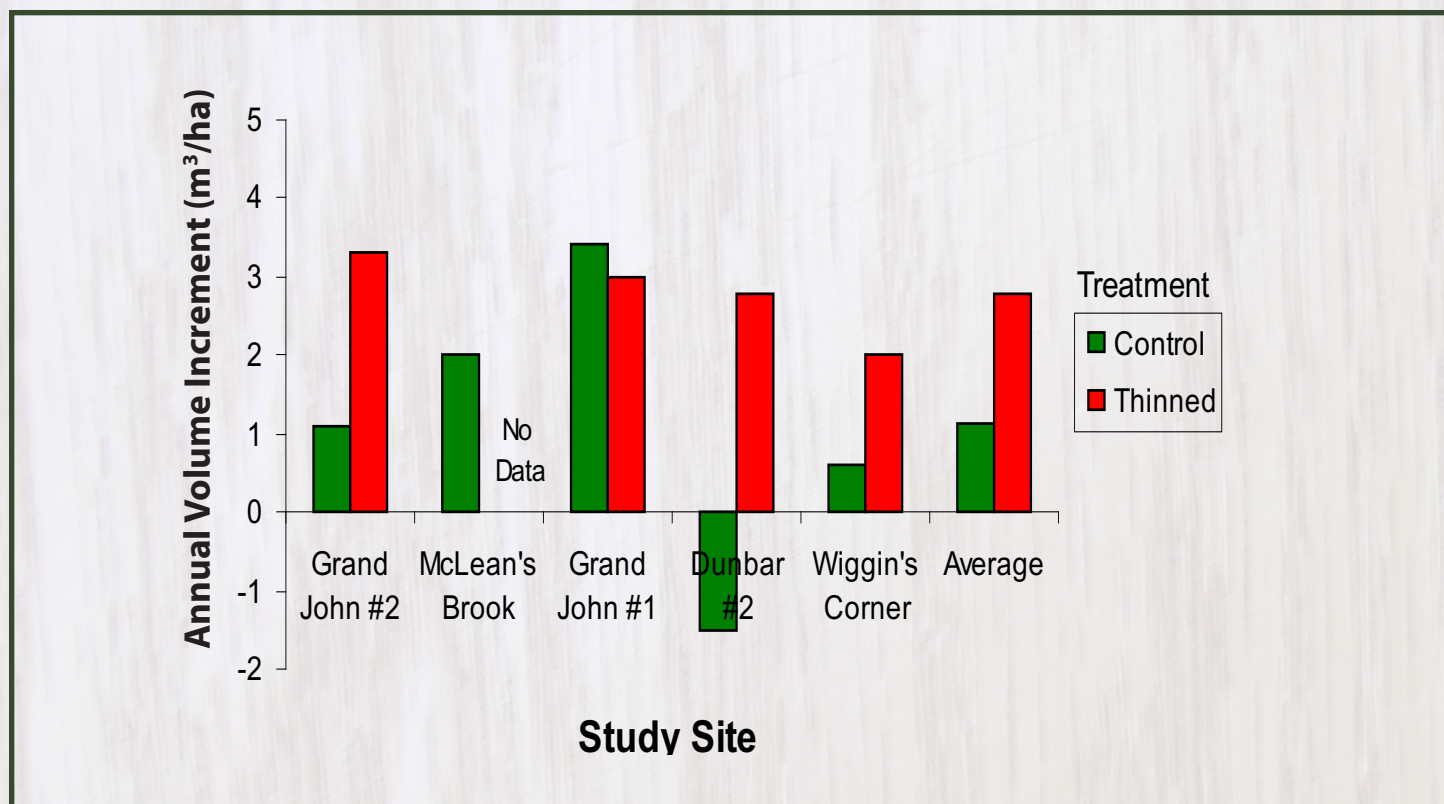


Figure 7. Average annual volume increment (m^3/ha) for the last 15 years by treatment and study site.

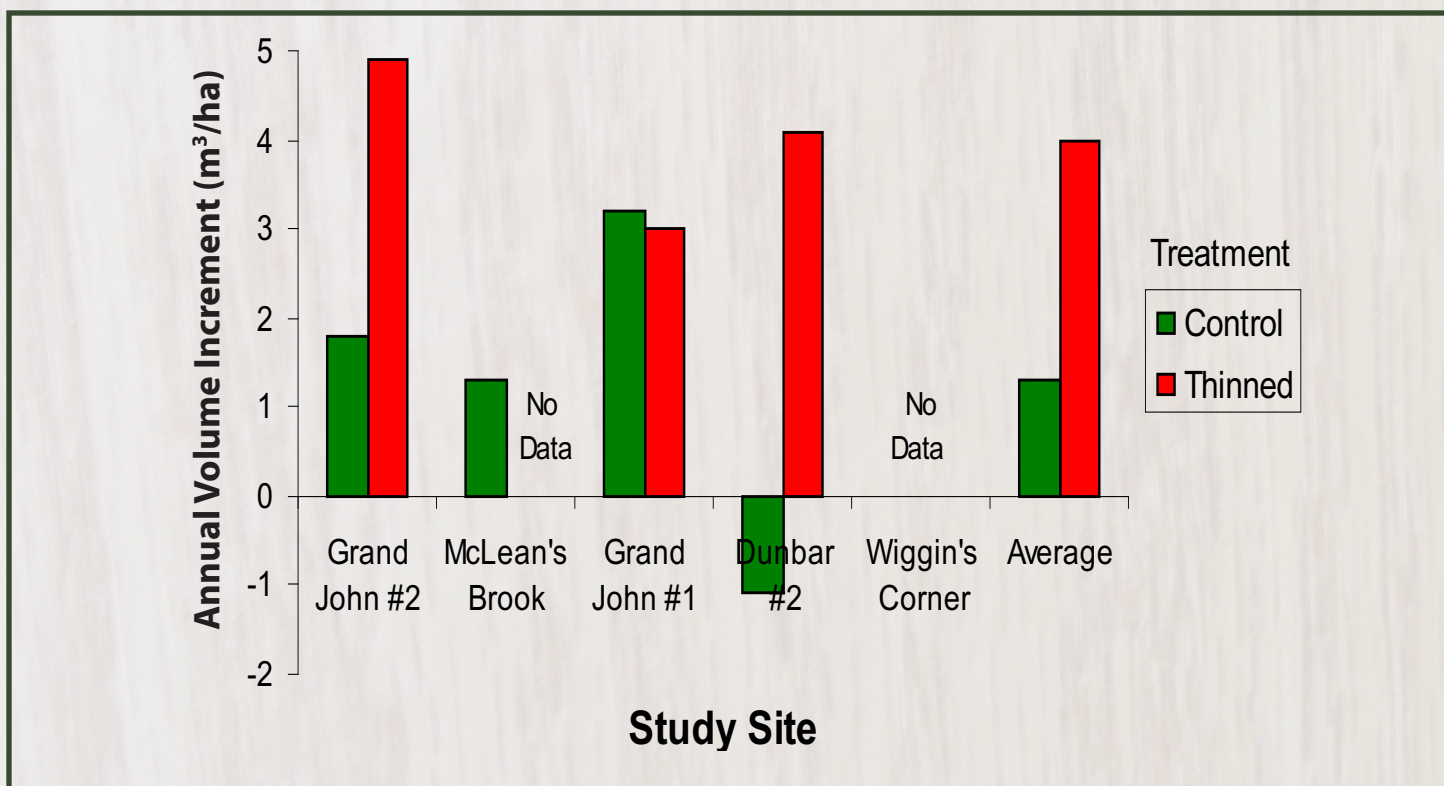


Figure 8. Average annual volume increment (m^3/ha) for the last 10 years by treatment and study site.

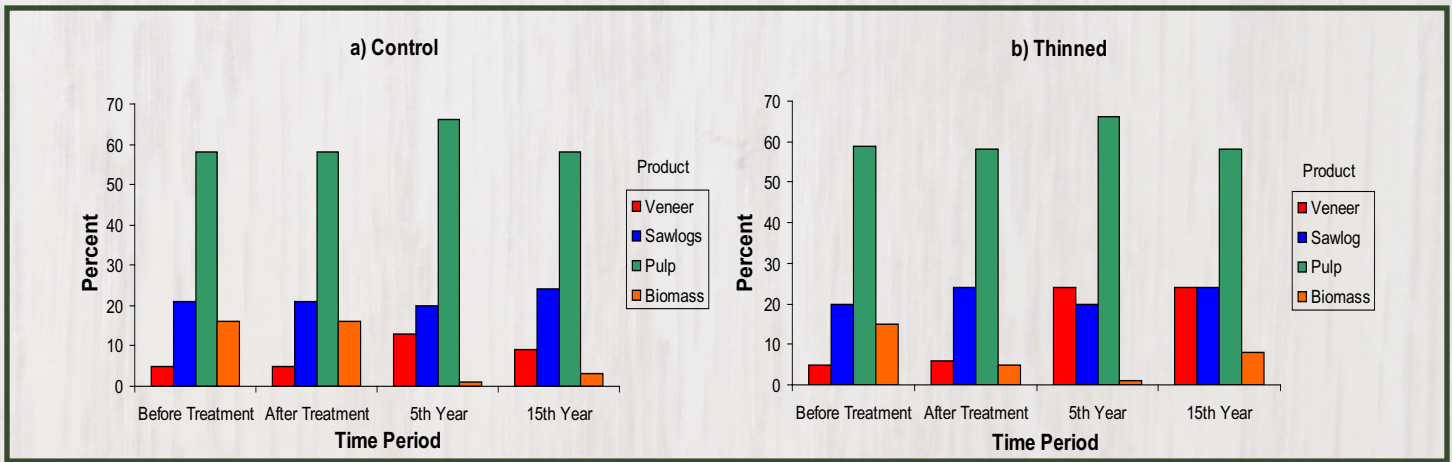


Figure 9. Tree product quality (%) using McDonald (1999) between the control (a) and thinned (b) plots for the measurement periods.

Tree Grade Changes

The control and thinned plots both exhibited similar trends of more valuable and desired forest products over time when assessed using a modified version of the New Brunswick (McDonald 1999) tree grade/product system (Fig. 9). Although the thinning treatments increased the percentage of veneer and sawlog quality trees compared with the control plots, the lower quality trees for pulpwood, fuelwood, and biomass products still dominated stand composition. Stand restoration in these second-growth northern hardwood stands is a slow process as these stands have only undergone one harvest intervention in the last 15 years. However, a more dynamic change in tree grades was observed over time when individual plots were examined (Table 4), which is an effect of combined factors such as initial stem quality, stem growth, mortality rates, harvest rates (both regulated and unregulated), species, and site quality.

Because of past events, only four study sites could be used to examine changes in external tree stem grade using the methods of Monger (2007). Also, the data could only be examined for the last measurement period (2008) because past tree grade measurements used only a modification of the methods of McDonald (1999). Similar trends in tree grade quality were observed between the two product grading systems (Figs. 9 and 10); namely, after one improvement harvest intervention, the stands are dominated by trees of low quality and product value. However, in some cases, the control plots had a higher occurrence of veneer and sawlog trees. The reason is likely because of the influence of site quality, removal of trees >40 cm dbh, species differences, and that Monger's (2007) is a more rigorous grading system. Wiedenbeck et al. (2004) report such differences in hardwood veneer log quality attributes in eastern North America. They attribute the cause of these differences to differences in: (1) log quality evaluation procedures, (2) requirements for product markets, and (3) regional quality characteristics of individual species to specific markets. Regardless of which system is used in this study, the observation is the same—stand restoration in these second-growth stands is a slow process that may not be achieved by a single improvement harvest intervention.

Table 4. Product potential as a percentage for the crop trees by study site, treatment, and measurement date using the methods of McDonald (1999, NBDNR) and Monger (2007, ABCD)

Study Site	Treatment	Year	NBDNR System				ABCD System			
			1	2	3	4	A	B	C	D
Grand John #2	Control	1993	5.8	31.7	55.8	6.7	–	–	–	–
		1998	10.9	13.4	75.6	0.0	–	–	–	–
		2008	7.4	11.5	81.5	0.0	1.6	4.9	14.7	78.7
	Thinned	1993*	5.5	21.1	66.4	7.0	–	–	–	–
		1993**	5.1	22.2	68.7	4.0	–	–	–	–
		1998	6.9	20.8	72.3	0.0	–	–	–	–
		2008	6.4	21.3	72.3	0.0	0.0	4.3	21.3	74.4
McLean's Brook	Control	1993	8.0	8.0	72.0	12.0	–	–	–	–
		1998	13.7	23.7	61.2	1.2	–	–	–	–
		2008	9.6	26.0	64.4	0.0	4.1	8.2	31.5	56.2
	Thinned	1993*	4.9	11.5	68.0	15.6	–	–	–	–
		1993**	7.3	17.1	65.8	9.8	–	–	–	–
		1998	11.4	22.9	61.4	4.3	–	–	–	–
		2008	–	–	–	–	–	–	–	–
Grand John #1	Control	1993	1.5	16.8	59.1	22.6	–	–	–	–
		1998	8.1	18.0	73.9	0.0	–	–	–	–
		2008	8.9	21.1	70.0	0.0	0.0	2.2	33.7	64.0
	Thinned	1993*	2.6	20.3	61.1	15.9	–	–	–	–
		1993**	3.6	24.1	65.1	7.2	–	–	–	–
		1998	15.3	19.7	64.8	0.0	–	–	–	–
		2008	17.2	23.4	59.4	0.0	1.6	9.4	25.0	64.0
Dunbar #2	Control	1993	5.7	23.6	53.7	17.1	–	–	–	–
		1998	20.4	29.6	48.2	1.8	–	–	–	–
		2008	16.9	32.5	50.6	0.0	0.0	11.1	27.2	61.7
	Thinned	1993*	7.9	22.7	54.5	14.8	–	–	–	–
		1993**	12.5	28.6	53.6	5.4	–	–	–	–
		1998	24.0	16.0	60.0	0.0	–	–	–	–
		2008	20.0	17.8	16.2	0.0	4.4	13.3	15.6	66.7
Wiggin's Corner	Control	1993	5.3	17.6	57.3	19.9	–	–	–	–
		2008	8.2	21.2	52.9	17.7	0.0	3.5	8.2	88.3
	Thinned	1993*	5.1	24.7	49.9	21.3	–	–	–	–
		1993**	4.0	28.2	48.3	19.5	–	–	–	–
		2008	3.5	30.1	45.1	21.3	0.0	0.0	8.0	92.0

* Before treatment

** After treatment

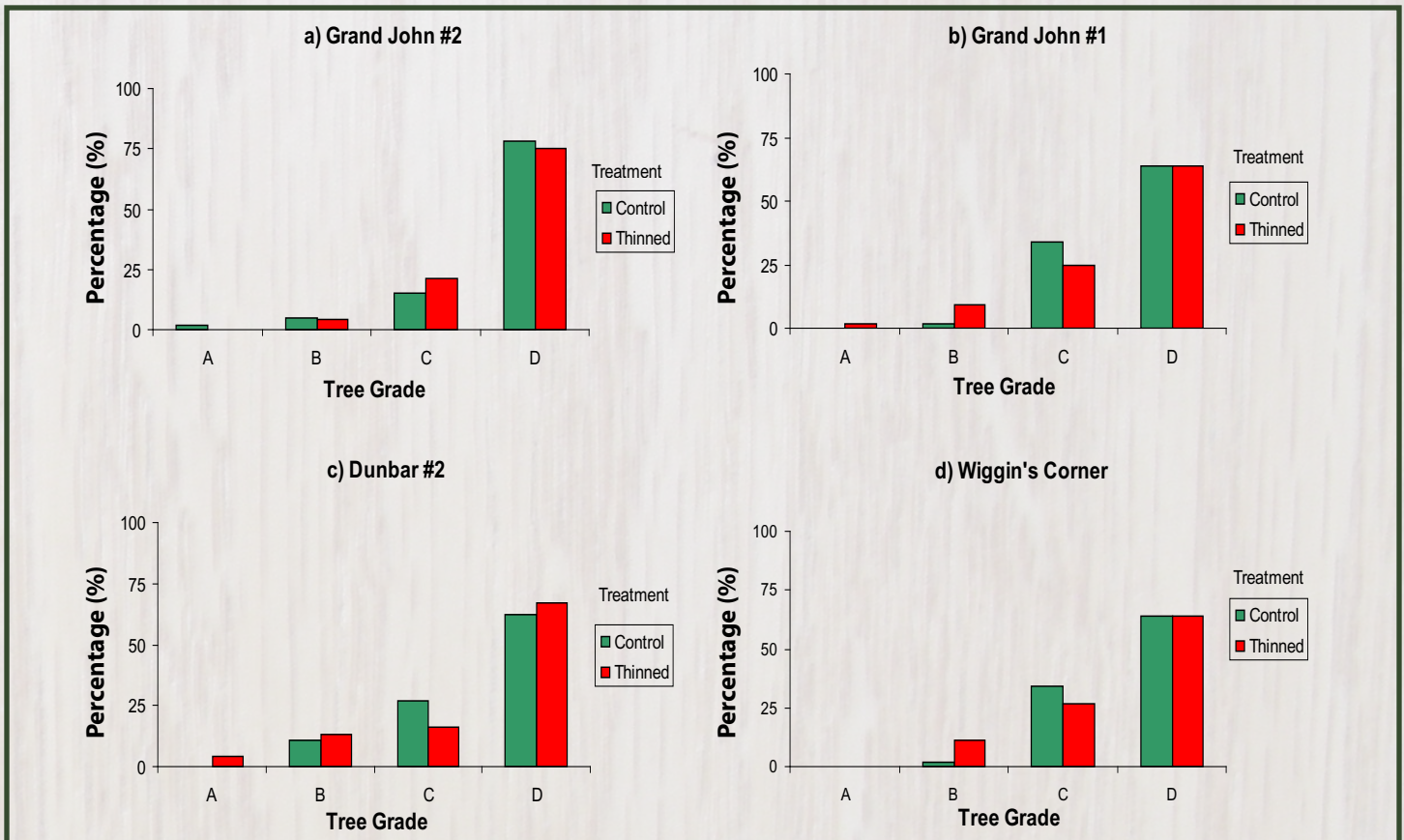


Figure 10. Tree product quality (%), after Monger (2007), between the control and thinned plots for four of the study sites 15 years after treatment.

Ingrowth Dynamics

Ingrowth was observed 5 years after the thinning treatments in only one of the study sites (Fig. 11). As expected, the density and occurrence of ingrowth increased after 15 years and was more pronounced in the thinned plots. This ingrowth is forming a second canopy of American beech and sugar maple in most of the study sites (Fig. 12). No ingrowth is present in the control plot at Grand John #2, but sugar maple dominates in the adjacent thinned plot. Sugar maple ingrowth dominates in the control and thinned plots at Grand John #1. Wiggin's Corner is the exception to the other study sites as its second-canopy composition contains both hardwoods and softwoods. Red maple, ironwood, balsam fir, and red spruce occur at this study site in addition to American beech and sugar maple. Such natural stand dynamics suggest that Wiggin's Corner has more of a mixedwood site characteristic and stand structure than the other four study sites. Leak et al. (1987) have a similar hardwood type for the northern hardwood forests of New Hampshire, USA.

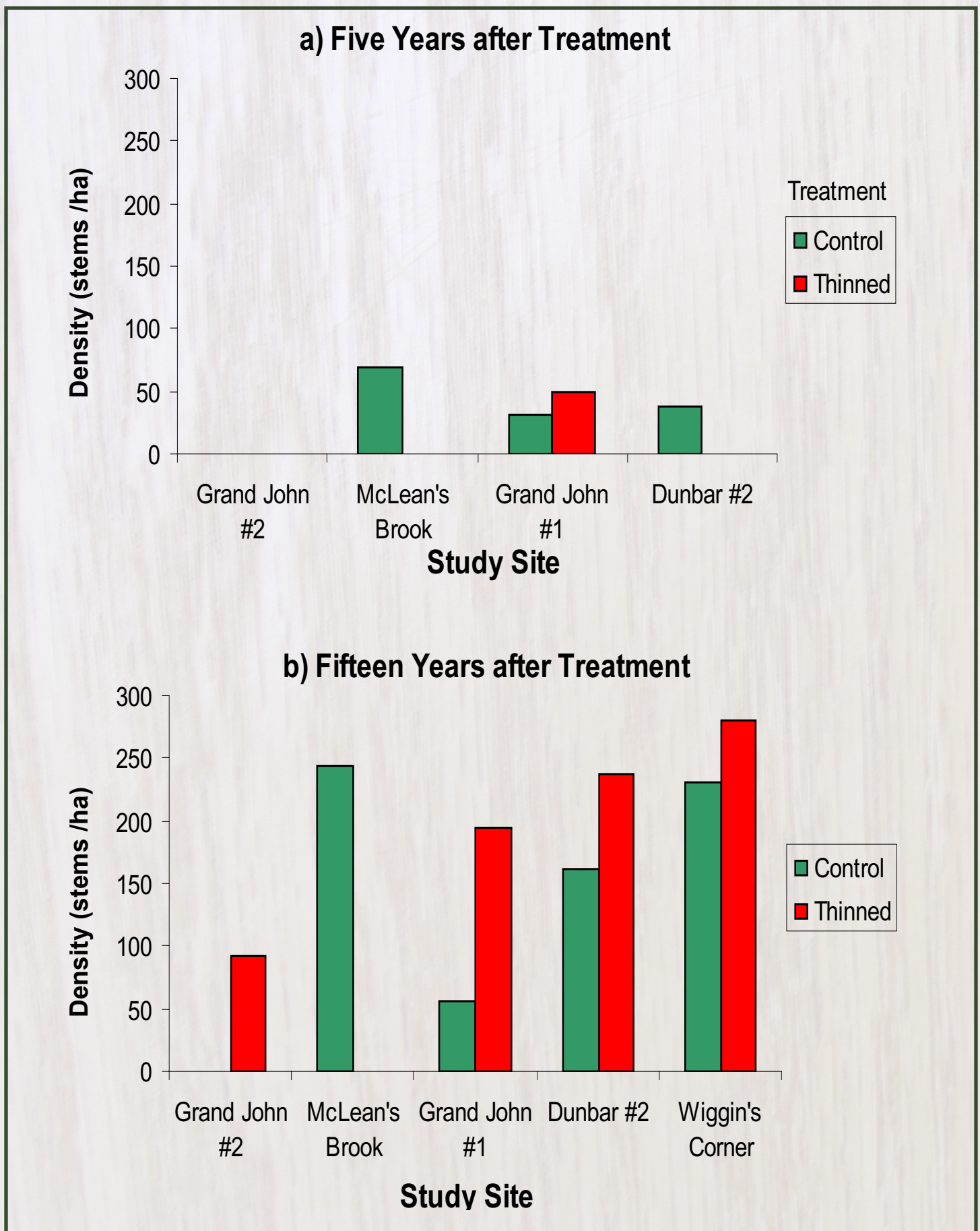


Figure 11. Occurrence of ingrowth (a) 5 and (b) 15 years after treatment, by treatment and study site.

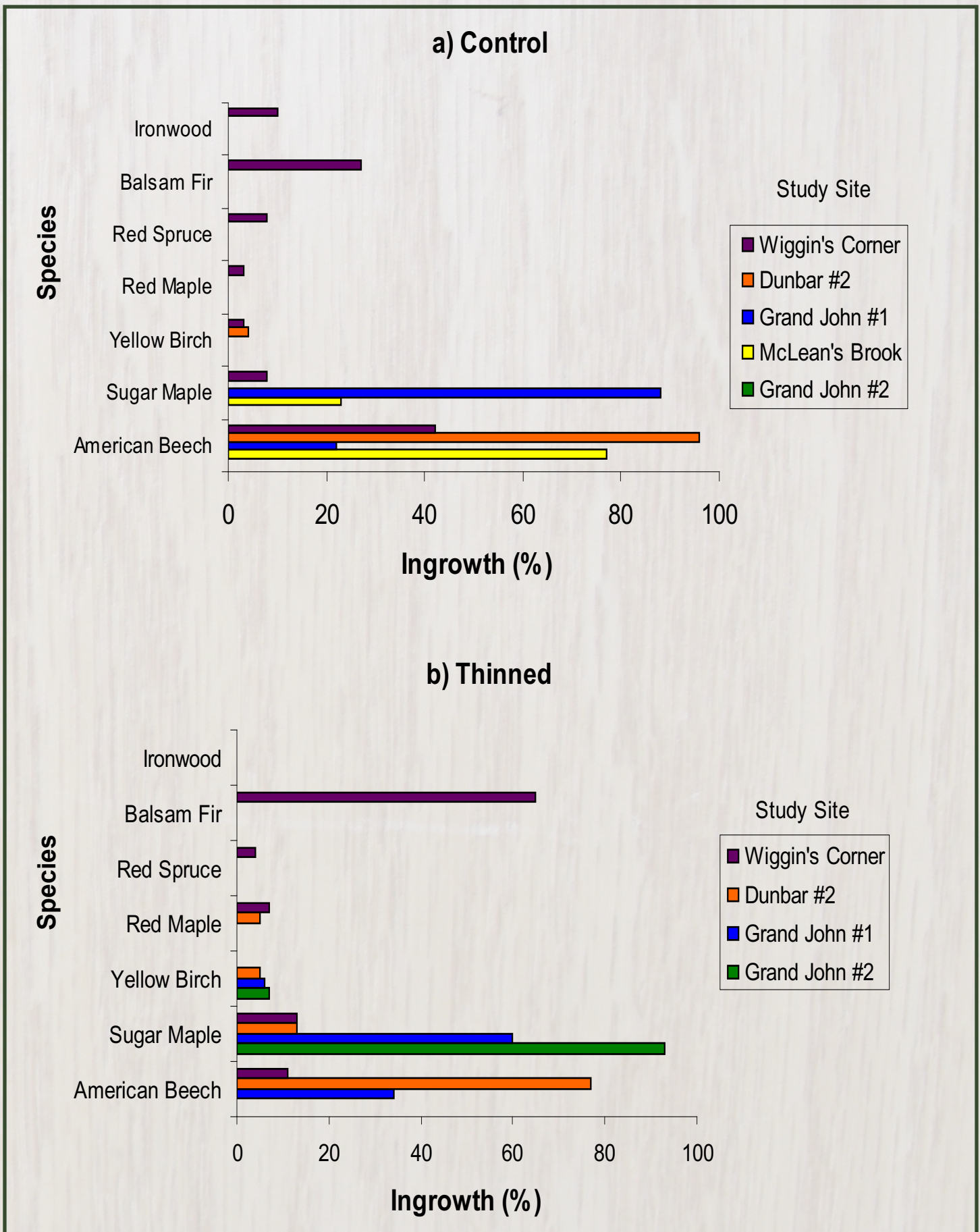


Figure 12. Occurrence of ingrowth in 2008 by treatment, study site, and species.

Discussion

Stand Dynamics

Volume increment

In the Maritime provinces, hardwoods tend to occur in mixed stands of conifers and deciduous species rather than in pure stands of one species (Rowe 1972, Lees 1978). The varied species composition, basal areas, and volumes for the study sites are representative of northern hardwood stands of this region and throughout the Northeast (Hornbeck and Leak 1992). The increased growth rates observed in the thinned stands after 15 years (Fig. 7) are in agreement with results from partial cyclic harvests in uneven-aged, shade-tolerant hardwood stands of Ontario: 0.4–0.6 m²/ha/yr basal area increments and 3.3 m³/ha/yr volume increments (Berry 1981, Anderson et al. 1990). Plonski (1974) predicts a mean annual volume increment of 2.4 m³/ha for northern hardwoods of Ontario. Periodic volume growth for mixed northern hardwood averages 4.2 m³/ha/yr in the Lake States (Godman et al. 1990). The values obtained in this study are within the same ranges as obtained in other studies from the Lake States (Erdmann and Oberg 1973, Crow et al. 1981). A gradual increase in the volume increment in thinned yellow birch–sugar maple stands has been observed in Quebec (Roberge 1987, 1988b).

The wide variation in the growth responses for the first 5 years, as shown for the annual volume increment growth, is the result of many factors (Fig. 6). This wide variation warrants a thorough analysis of the impact of changes in stand density on volume for each site class. Time is required for the residual trees to adjust to the new environment created by the partial harvest treatments. The residual trees need to expand their crown areas and root systems to occupy the growing space provided by the removal of competing trees (Robertson and Myketa 1998). Once the residual trees have developed new crown areas and roots, increased growth in the partially harvested stands will occur (Fig. 8). Jones and Thomas (2004) observed that sugar maple trees in uneven-aged northern hardwood stands of central Ontario have a 3- to 5-year lag time for growth response after treatment. However, studies in Quebec have shown that diameter growth is noticeable 2 years after treatment for selection harvest (Forget et al. 2007). American beech exhibited the greatest growth response, followed by yellow birch and sugar maple in that study. Sugar maple of intermediate size showed the largest proportional diameter increment response. Another factor that contributes to the variation in growth response of the thinned stands is that stem diameter growth patterns are very variable across the diameter classes within a stand because of site, species composition, stand structure, and silvicultural treatment differences (Erdmann and Oberg 1973, Roberge 1987, 1988b, Leak 2004). Roberge (1987, 1988b) observed both increases and decreases in mean annual volume increment for control plots in a yellow birch–sugar maple stand because of hardwood species differences and softwood mortality. In the same study, individual growth rates of thinned plots were influenced by the proportions of the various tree species. Crow et al. (1981) also report a wide variation in volume growth between partial removal treatments and replications in a sugar maple-dominated stand in northern Michigan, USA. Negative volume growth was reported for the first 5-year period of this study (Crow et al. 1981). Roberge (1975) attributes some of the negative growth in his study to heavy removal causing shock to some of the residual trees. Some of the partial removal treatments exhibited negative growth in the first 5-year period. However, improvements in tree stem grade and tree size should be given more emphasis than diameter and volume growth in forest management prescriptions, as these factors have a greater impact on the value of the stand (Roberge 1975, Leak et al. 1987).

Basal area

Basal area growth showed similar results as volume growth in the stands of this study. This wide variation again suggests the need for a thorough analysis of the impact of changes in stand density on basal area for each site class. Initial basal area values (22.9–29.3 m²/ha) (Fig. 2) are close to those reported for mixed northern hardwoods of the Lake States: 27.6–36.8 m²/ha, with a few older stands exceeding 45.9 m²/ha (Godman et al. 1990). The basal area values are within the ranges obtained in second-growth northern hardwood stands in Quebec (Bédard and Majcen 2001, Hartmann et al. 2009) and in New England (Solomon 1977). Both this study and that of Bédard and Majcen (2001) show a greater response in basal area for the treated plots compared with control plots (Fig. 5). Unlike Bédard and Majcen (2001), some of the control plots exhibited decreases in basal area over time. The lower value of 22.9 m²/ha may be partly caused by poor drainage conditions at Wiggin's Corner (Study Site 6) and the more "mixedwood" nature of this site compared with the other study sites. Leak et al. (1987) classify similar stands in the Northeast as mixedwood types as opposed to stands that contain more shade-tolerant hardwoods such as the beech–birch–maple and beech–red maple types. Site conditions have a pronounced effect on stand productivity that is expressed by total basal area and volume (Gevorkiantz and Duerr 1937, Godman et al. 1990).

As with mean volume increment, the levels of basal area for the study sites were not only influenced by the intensity of the thinning treatment and residual basal area (Figs. 2, 3, and 5), but also by many other factors, which again suggests the need for further examination of the influence of site differences on the temporal change of stand density and these other factors. Analysis from uneven-aged northern hardwood stands in eastern Ontario has shown that growth response is maximized at a residual basal area of approximately 14 m²/ha for trees >24 cm dbh (Ontario Ministry of Natural Resources (OMNR) 1983). Studies further south in the Lake States suggest a residual basal area of 16 m²/ha for residual trees >24 cm dbh (Eyre and Zillgitt 1953, Arbogast 1957, Crow et al. 1981). Growth across the range of stem sizes may change with future stem removals (Leak 2004). Leak et al. (1987) recommend a minimum basal area of 14.9–17.2 m²/ha (65–75 ft²/ac) of trees >12.7 cm (5 in.) for northern hardwood stands of the Northeast under uneven-aged management. On better sites, the residual basal area should be higher, around 18.4 m²/ha (80 ft²/ac) to promote timber quality development. Leak and Gove (2008) recommend moderate stand densities of 14.9–18.4 m²/ha (65–80 ft²/ac) for beech–red maple–birch–hemlock stands of moderate vigor and quality in New Hampshire, USA. Further analysis of these data may reveal the stocking levels necessary to produce increased diameter growth for high-quality hardwood stems.

Differences observed in the patterns of basal area development for the control plots could be caused by a number of factors. As stated earlier, northern hardwood stands are dynamic and variable across diameter classes because of differences in site, species composition, stand structure, and silvicultural treatments (Erdmann and Oberg 1973, Solomon 1977, Roberge 1987, 1988b, Leak 2004). The proximity of harvest and extraction trails has been shown to have a negative (Hartmann et al. 2009) or insignificant (Forget et al. 2007) effect on tree growth and survival. The negative effect on tree growth can vary with crown class and tree size (Hartmann et al. 2009). Fournier et al. (2006) attribute the variable basal area responses for a selection harvest in eastern Ontario to a high post-harvest mortality rate and slow growth rate of the surviving trees. Many of the surviving trees had harvest wounds. Nyland (1994) and Caspersen (2006) reported increased stand mortality after partial harvest because of increased stress and harvesting wounds to the residual trees. Acid rain deposition and air pollution have caused recent calcium and magnesium deficiencies on some forest sites in eastern North America (Horsley et al. 2000, 2002, Juice et al. 2006, Patterson et al. 2012). Such nutrient deficiencies have resulted in crown

dieback and tree mortality. Defoliation by the forest tent caterpillar (*Malacosoma disstria* Hübner) can cause severe declines in growth and increase mortality in sugar maple, this insect's preferred host (Wood et al. 2009). Defoliated sugar maple trees often show signs of crown dieback. Resilience to the defoliation varies within and among stands that contain sugar maple. Defoliation can also cause tree grade reductions for sugar maple in stands where timber improvement treatments have been conducted by partial harvests (Wink and Allen 2007). The increased occurrence of epicormic branching along the stem of dominant and co-dominant trees after a forest tent caterpillar outbreak ceases is a cause of value losses in these stands. In the Maritime provinces, severe forest tent caterpillar outbreaks occur periodically (Magasi 1995, Simpson and Coy 1999). Records indicate that severe defoliation occurred in the study area between 1980 to 1984 and again from 1992 to 1995 (Magasi and Hurley 1994, Simpson and Coy 1999). However, no direct measurements of forest tent caterpillar population levels or defoliation of the trees were recorded during the study period. As with spruce–balsam fir stands of New Brunswick that were defoliated by spruce budworm (*Choristoneura fumiferana* Clem.) (Simpson and Coy 1999), hardwood stands, where investment has occurred for increased stand value, may require some form of “protection” from pests such as the forest tent caterpillar. None of above suggested factors has been directly examined in this study, and thus, future research is needed.

Stem diameter growth

The classic “chainsaw” effect of increasing the average stand diameter in the treated plots was not observed because of the removal of trees >40 cm dbh (Fig. 4). However, the residual trees of the thinned plots showed increased diameter growth that is consistent with other studies in northern hardwoods of eastern Canada (Roberge 1988b, Anderson et al. 1990, Bédard and Majcen 2001, 2003, Fortin et al. 2009), the Lake States (Erdmann and Oberg 1973, Crow et al. 1981, Gronewold et al. 2012) and the Northeast (Trimble 1968, Solomon 1977, Leak et al. 1987). As a general rule, the greater the intensity of the harvest removal, the greater the diameter response of the residual trees. Sugar maple of intermediate size showed the greatest proportional diameter increment response in a study from Ontario (Jones and Thomas 2004). Bédard and Majcen (2001) also observed different growth responses across diameter classes. Leak (2004) reports that diameter growth response varies by diameter class and species, and is dependent on site conditions. For stands under light selection harvests or high stem densities, Nyland (1987) and Erdmann and Oberg (1973) observed that diameter growth increases to a maximum with stem diameter size and then declines.

Solomon (1977) reported that yellow birch and red maple showed the greatest diameter response, followed by sugar maple and American beech in second-growth northern hardwood stands in New Hampshire. Roberge (1987, 1988b) observed that yellow birch displayed greater diameter responses than sugar maple in a yellow birch–sugar maple stand. The same relationship between yellow birch and sugar maple was observed in the Lake States (Crow et al. 1981). However, in another study in Quebec that examined a sugar maple–yellow birch stand, sugar maple exhibited greater diameter growth than yellow birch (Roberge 1988a). Likewise, Erdmann and Oberg (1973) observed that sugar maple exhibited greater diameter growth than yellow birch in sugar maple-dominated stands of northeastern Wisconsin, USA. These results show the importance of site requirements for individual species for stand dynamics in northern hardwood stands. Roberge (1975) observed variable diameter growth responses between sugar maple and yellow birch depending on the measurement period. He observed best growth with co-dominant and intermediate trees that were influenced by the degree of release from competing trees. Studies in Quebec showed an average of 3 cm growth in 10 years across all diameter classes (Bédard and Majcen 2001, 2003). According to Anderson et al. (1990), sugar maple exhibited slow to moderate but persistent diameter growth of 2.5 cm over 10 years for mature

trees in unmanaged stands. Diameter growth of yellow birch tends to be moderately low in unmanaged stands. Fortin et al. (2009) reported that only a few trees (13%) did not migrate to a higher diameter class, and most trees (74%) gained 2–4 cm from a study in Quebec. In addition to species composition and site having an impact on diameter response, the age of the trees also influences diameter growth (Godman et al. 1990). Godman (1957) provides examples of mature sugar maple stands growing at a slower rate than trees in younger stands. As the average diameter of the residual trees is increasing in both the control and thinned plots, the stands of the study sites have not reached a stabilization period of stand development for uneven-aged structures (Roberge 1988b).

Tree Grade Changes

The objective of commercial thinning and partial harvesting has traditionally been to improve and increase the amount of higher quality stems for sawlog and veneer products (Lees 1978, Miller et al. 2003, Webster et al. 2009, Gronewold et al. 2012). A recent study in the northern hardwood stands of the Lake States suggested that large trees increase in value when they become veneer quality, but quality criteria for these trees can vary greatly (Webster et al. 2009). Commercial thinning and partial harvesting have been used for the restoration of high-value northern hardwood stands with high-quality stems (MacLean 1950, Roberge 1975). Such commercial objectives of uneven-aged management tend to result in the removal of some features of stand structure associated with old-growth hardwood forests such as cavity trees, snags, and large legacy trees (Kenefic and Nyland 2007, Gronewold et al. 2010). The more intense the harvesting of residuals and poor-quality stems, the greater the impact of uneven-aged management systems on the complex structure of old-growth northern hardwoods. Both Vanderwel et al. (2008) and Gronewold et al. (2010) observed that >20-year harvesting interventions tend to have minor influences on the non-commercial structural features of northern hardwood stands. In a more recent study, Gronewold et al. (2012) observed that, in northern hardwoods of Michigan under single-tree selection, average tree grade was relatively unaffected by residual stocking levels after 50 years. The 20-year harvest intervention cycle is greater than the recommended 15-year cycle for the Northeast (Leak et al. 1987). Perhaps modifications of the selection criteria for tree removal should be included in future harvest interventions to maintain some of the stand structural features of old-growth hardwood stands.

There are numerous studies and field trials that demonstrate increased tree growth and utilization, but few have examined how these silvicultural treatments impact tree grade quality (Miller et al. 2003). Although analysis of the information from this study is not complete, preliminary results show that increases in the frequency of quality stems with more valuable products is a slow process in northern hardwood stands that have had repeated unregulated harvests for a desired product without regard to future stand dynamics and value (Figs. 9 and 10). The stands of this study have only received one harvest intervention that removed the worst of the degraded trees on a 20-year harvest cycle. Sendak and Leak (2000) report similar variation in tree quality approximately 40 years after an initial partial harvest in second-growth northern hardwood stands in the White Mountains of New Hampshire, USA. They attributed the variation to differences in species composition and initial basal areas and volumes. More frequent harvest interventions would hasten the development of high-value stands for sawlogs and veneer production, but such actions may not always be economically viable or able to maintain desired stand structure. Information exists in the literature to assist the forester with decisions for improving degraded hardwood stands (i.e., Kenefic and Nyland 2006, Nyland 2003, 2006, Clatterbuck 2010). Depending on the condition of the northern hardwood stand, forest restoration practices may be a slow process or may not be economical.

For partial removals or commercial thinnings, Miller et al. 2003 reported that increases in tree grade only occurred for specific hardwood species in a mixed hardwood stand in West Virginia, USA. Black cherry (*Prunus serotina* Ehrh.), red oak (*Quercus rubra* L.), and yellow poplar (*Liriodendron tulipifera* L.) showed improvement after treatment because of increased growth and the retention of large, high-quality trees, whereas red maple and white oak (*Quercus alba* L.) exhibited no improvement in tree grade because of poor-quality residual trees. An examination of a wide variety of thinning treatments in white oak stands located in Kentucky and Ohio revealed differences among study sites for tree grade improvement (Brown et al. 2004). In some cases, the intensity of the thinning treatment had an influence on tree grade quality. Strong et al. (1995) report that the medium intensity for harvest removal of 17.2 m²/ha (75 ft²/ac) provided the best average tree grade changes except for crop tree release. However, tree grade increased over time in all of the single-tree selection treatments in sugar maple-dominated stands. The medium removal for single-tree selection also had high rates of return, but heavy removal (13.8 m²/ha or 62 ft²/ac) provided the greatest rate of return (Niese et al. 1995). The accuracy of tree grade projections was examined for five Appalachian hardwoods in West Virginia 12–15 years after commercial thinning (Miller et al. 2008). Differences among species and treatments were assessed for accuracy of tree grade projections. Some species, such as black cherry and red oak, exhibited less accuracy for the thinned stands because of harvest wounds and epicormic branches. Tree grade projections were less accurate for large, higher quality trees than for smaller trees of lower quality. An assessment of residual tree quality for the two-aged silvicultural system in 20 Appalachian hardwood stands showed that the largest reductions were caused by epicormic branches and harvesting wounds (Johnson et al. 1998). The frequency of harvesting wounds was influenced by season of harvest. Tree wounds from harvesting were more frequent and severe during spring and summer than for operations conducted during fall and winter. Improvement for species composition and tree grade can have a long-term impact in northern hardwoods of the Northeast. Leak and Sendak (2002) document an increase of grades 1 and 2 butt logs of 30% for American beech and 65% for sugar maple after 41 years for a study that received three single-tree selection harvests at 20-year intervals. Fournier et al. (2006) report a two-fold increase of acceptable growing stock 20 years after the first harvest intervention in a selection cut in Ontario. Hence, any system of predicting or projecting tree grade or future quality of standing trees will show some degree of inherent variability. Such variable information can nonetheless be incorporated into stand yield curves to predict potential tree value changes and assist foresters in deciding which trees to leave when conducting partial harvesting prescriptions. For example, Myers et al. (1986) developed regression equations that predict butt-log grade distributions from inventory information for five Appalachian hardwood species. For the northern hardwood forest of the Northeast, Yaussy (1993) developed logistic regression prediction equations for 20 species groups that could be incorporated into individual tree growth and yield simulators such as NE-TWIGS and FVS. Because of the need to separate and predict hardwood log quality into different products and uses, several log-grading systems have been developed in Quebec, and three of the current systems were evaluated by Fortin et al. (2009). All three methods were better at distinguishing log grade than tree volume. As expected, the “true” tree grade classification method proved to be the best system based on Akaike and Bayesian information. Information from this study could be used to develop initial tree grade prediction equations for current growth-and-yield simulators used by the New Brunswick Hardwood Technical Committee. The Nova Scotia Department of Natural Resources has integrated tree grade information into their inventory procedures (Keys and McGrath 2002).

Ingrowth Dynamics

The abundance of American beech as the main component in the understorey (Figs. 11 and 12) has been widely observed and documented throughout the range of northern hardwoods (Tubbs and Houston 1990, Robertson and Myketa 1998, Nelson and Wagner 2011). The potential increase of American beech in northern hardwood stands after natural disturbances and harvesting is a forest management concern because of the resulting negative impacts on future fibre supplies and annual allowable cut (Nelson and Wagner 2011). Because of the low light requirements and large amounts of frequently produced seed, American beech has the ability to dominate the regeneration layer as advance regeneration in northern hardwood stands (Tubbs and Houston 1990). Single-tree selection tends to promote American beech and sugar maple, as the regeneration of these species has the ability to penetrate through hardwood leaf litter and tolerate the low light conditions (Berry 1981, La Rocque 1985, Robertson and Myketa 1998). In small isolated gaps, American beech out-competed sugar maple regeneration and saplings in both the control and thinned stands (Jones et al. 1989, Tubbs and Houston 1990, Bohn and Nyland 2003, Nolet et al. 2008). Light-seeded species such as yellow and white birch often require additional site preparation to remove the hardwood leaf litter of sugar maple and American beech leaves and mix the humus and mineral soil. These two birch species also require the increased light conditions provided by gap harvesting techniques used in uneven-aged silvicultural systems for northern hardwood stand types. The increased area of the gaps compared with single-tree selection also allows a variety of site preparation methods to provide the seedbed requirements for light-seeded species such as yellow and white birch (Erdmann 1990, Robertson and Myketa 1998, Leak et al. 1987, Leak 1999). Loucks (1962) states that site preparation is required to promote yellow birch regeneration on partial cuts in the Maritimes Uplands Region where some of the study sites occur. The occurrence of sugar maple and yellow birch on some of the study sites (Fig. 12) was caused in part by large gaps and extraction trails that received adequate site preparation from the harvested stems being dragged with a cable skidder. Examination of the maps for the thinned plots shows a combination of small gaps (less than one tree length) and large gaps (less than two tree lengths) that were created throughout the harvest sites. In addition to the gaps receiving the required seedbed requirements, the open areas provided the required light conditions for the moderately shade-tolerant yellow birch regeneration. It is also possible that some of the advance American beech and sugar maple regeneration was destroyed by the extraction of harvested stems. All study sites were harvested between September and December 1993. According to Tubbs and Reid (1984) the season of harvest can have an influence on regeneration and resulting ingrowth. If a hardwood stand is harvested in summer, adequate ground scarification generally occurs for yellow birch, and some of the advance regeneration will be damaged or destroyed. Winter harvesting operations tend to preserve advance regeneration and do not produce the required ground disturbances required by birch species. The occurrence of heavy seed years during a harvest operation may change these regeneration trends in northern hardwood stands. As snow levels would not be deep during the end period of harvesting operations, a combination of site disturbance, protection of small regeneration, and destruction of large regeneration would have occurred. Sugar maple is known to inhibit the growth of yellow birch when root growth periods of the two species overlap (Tubbs 1965). According to (Smith 1986) and Anderson et al. (1990), group selection harvest methods are known to produce small, even-aged patches of shade-intolerant and moderately shade-tolerant species as a matrix within uneven-aged stands dominated by stand-tolerant species as is the case at the Dunbar #2 site. Without natural and harvesting disturbances, yellow birch and white birch components within a northern hardwood forest will be reduced and will eventually disappear from the landscape (Leak and Yamasaki 2010).

Removal of American beech is often accomplished by aerial or ground-based application of chemical herbicides, but it may cause additional vegetation competition problems (Robertson and Myketa 1998). Smallridge and Nyland (2009) provide one of the many guidelines available for the control of American beech in northern hardwood stands. In a series of articles, Nyland et al. (2004) provide the ecology of the major competing trees and shrubs in northern hardwood stands and the effects of such control methods (Nyland et al. 2006). Recent research has shown that American beech is more susceptible to some herbicides than sugar maple, red maple, and yellow birch (Nelson and Wagner 2011). Presently, the New Brunswick Department of Natural Resources uses small patch cuts (irregular circles or strips) to control and reduce the abundance of American beech in northern hardwoods. The increased light levels and ground disturbance within these small patch cuts measuring 0.04 to 0.24 ha. reduces the American beech understorey while promoting other species such as sugar maple and yellow birch (Erdmann 1990). The treatment was developed and tested in New Brunswick on advice received from Dr. William Leak, USDA Forest Service at Durham, New Hampshire. Leak and Filip (1977) were among the first to record the results of such treatments in the northern forests of the White Mountains in New Hampshire, USA. Leak and Yamasaki (2010) also observed that with proper management techniques American beech can form part of a healthy and productive component of northern hardwood stands.

Conclusions

Stand Dynamics

The variable stand conditions and removal rates produced variable growth responses, consistent with the literature that was reviewed and examined.

The greater the basal area removal, the greater the diameter response of individual residual trees in the thinned plots. However, growth response may not reach former basal area or volume levels if too many trees are removed during harvest.

The thinned stands have not recovered the basal area values that existed at the start of this study. However, this management goal may not be as important as a targeted or desired basal area level set by foresters, especially when stand value may be of greater importance than volume increases, depending on markets and stand management objectives.

Past predicted annual volume increment growth rates of 2.4 m³/ha/year were verified in this study for the control stands.

Annual volume increment growth rates suggest that hardwood stands subjected to partial removals produced better growth responses than were predicted at the start of the original study.

Annual volume increment growth rates exhibited a wide variation between and among treatments for many potential factors. Identification and refinement of these factors may produce greater growth responses than the average values observed in this study.

Hardwood stands, especially those where investments have been undertaken for increased product value, may require some form of “protection” from pests such as the forest tent caterpillar, if the desired growth and growth rates are to be achieved.

Hardwood stand dynamics are complex, and increasing our knowledge of these dynamics is required to better understand their impacts on growth and development.

Tree Grade Changes

Stand restoration and stem quality improvement are slow processes that may not be achieved with a first harvest entry in second-growth northern hardwood stands that have had the higher quality trees repeatedly removed in the past.

Changes in tree grades were observed to be very dynamic in these second-growth northern hardwood stands because of a number of factors, such as initial stem quality, stem growth, mortality rates, harvest rates (both regulated and unregulated), species, and site quality.

Differences between tree grading systems are evident in the higher quality products. These differences need to be addressed for regional quality characteristics and market requirements for the present and future.

Ingrowth Dynamics

In general, ingrowth occurred more frequently in the thinned stands than the control stands.

Except for the “mixedwood” characteristics of the Wiggin’s Corner site, ingrowth does not exist as a diverse mixture of desired tree species but as a secondary canopy of American beech and sugar maple.

Recommendations

Stand Dynamics

As the annual volume increment growth rates suggest that hardwood stands grow better than predicted, additional studies are required for verification and to determine the potential impact on the annual allowable cut and the optimum removal rate for a specific stand type and site condition.

As the growth rates were influenced by a variety of potential factors, identification and refinement of these factors need to be undertaken in order to determine the impact on growth responses at the landscape level.

The influence of site quality on the temporal change of stand density should be examined in a future study.

Tree Grade Changes

As changes in tree grades at the plot level were observed to be very dynamic, this factor needs to be quantified at the individual tree and species levels and the information incorporated into the management process for wood supply. Thus, it is suggested that a new grading system that incorporates tree vigor be considered for New Brunswick, such as the four-class system that was once used in Quebec.

Tree grading systems need to address differences in regional quality characteristics and market requirements for the present and future.

A national tree grading system needs to be developed and adopted by resource managers across eastern Canada to allow national comparisons and evaluations.

Ingrowth Dynamics

Unless another silvicultural system or additional silvicultural prescriptions are used to produce new cohorts of desired crop trees, these uneven-aged structured stands will develop a second canopy dominated by American beech and sugar maple—except for sites that have a mixedwood (softwood and hardwood) site characteristic. Increased soil scarification and frequency of large gaps is required to increase the frequency of yellow birch into the ingrowth cohort diameter classes.

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Literature Cited

- Anderson, H.W., Batchelor, B.D., Corbett, C.M., Deugo, D.T., Husk, C.F., and Wilson, W.R.** 1990. *A silvicultural guide for the tolerant hardwoods working group in Ontario*. Ontario Ministry of Natural Resources, Forest Resources Group Science and Technical Series Volume 7.
- Arbogast, C. Jr.** 1957. *Marking guides for northern hardwoods under the selection system*. Paper 56. USDA Forest Service, Lake States Forest Experiment Station, St. Paul, Minnesota, USA.
- Bédard, S., and Majcen, Z.** 2001. Ten-year response of sugar maple-yellow birch-beech stands to selection cutting in Quebec. *Northern Journal of Applied Forestry* **18**(4): 119–126.
- Bédard, S., and Majcen, Z.** 2003. Growth following single-tree selection cutting in Quebec northern hardwood. *The Forestry Chronicle* **79**(5): 898–905.
- Berry, A.B.** 1981. *A study in single-tree selection for tolerant hardwoods*. Information Report PI-X-8. Natural Resources Canada, Canadian Forest Service - Petawawa National Forestry Institute, Chalk River, Ontario, Canada.
- Bohn, K.K., and Nyland, R.D.** 2003. Forecasting development of understory American beech after partial cutting in uneven-aged northern hardwood stands. *Forest Ecology and Management* **180**(1–3): 453–461.
- Boyce, J.S.** 1961. *Forest pathology*. Third edition. McGraw-Hill Book Company, New York, New York, USA.
- Brown, J., Miller, G.W., and Gottschalk, K.W.** 2004. Effects of alternative thinning treatments on tree grades at three upland hardwood sites in Kentucky and Ohio: 30 year results. Page 520 in D.A. Yaussy, D.M. Hix, R.P. Long, and P.C. Goebel, editors. *Proceedings, 14th Central Hardwood Forest Conference*. General Technical Report NE-316. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Caspersen, J.P.** 2006. Elevated mortality of residual trees following single-tree felling in northern hardwood forests. *Canadian Journal of Forest Research* **36**(5): 1255–1265.
- Clatterbuck, W.K.** 2010. *Treatments for improving degraded hardwood stands*. University of Tennessee Cooperative Extension Publication FOR-104. University of Tennessee, Knoxville, Tennessee, USA.
- Crow, T.R., Tubbs, C.H., Jacobs, R.D., and Oberg, R.R.** 1981. *Stocking and structure for maximum growth in sugar maple selection stands*. Research Paper NC-199. USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota, USA.
- Duchesne, I., Ung, C.-H., Swift, D.E., and Ferland-Raymond, B.** 2012. *Hardwood Initiative—Part 5: Development of new processes and technologies in the hardwood industry: Project 16 – Towards a Forest Inventory Capable of Predicting the Properties and Economic Value of Hardwoods in Eastern Canada. Development of a Product Matrix by Tree Grade and DBH class for Sugar Maple and Yellow Birch*. FPIinnovations Partner Report. FPIinnovations, Ste-Foy, Quebec, Canada.

- Erdmann, G.G.** 1990. *Betula alleghaniensis* Britton. Yellow birch. Pages 325–332 in R.M. Burns and B.H. Honkala, technical coordinators. *Silvics of North America: Volume 2. Hardwoods*. USDA Forest Service Agricultural Handbook 654. USDA, Washington, D.C., USA.
- Erdmann, G.G., and Oberg, R.R.** 1973. *Fifteen-year results from six cutting methods in second-growth hardwoods*. Research Paper NC-100. USDA Forest Service, North Central Forest Experiment Station, St. Paul, Minnesota, USA.
- Eyre, F.H., and Zillgitt, W.M.** 1953. *Partial cuttings in the northern hardwoods of the Lake States*. Technical Bulletin LS-1076. USDA Forest Service, Lake States Forest Experiment Station, St. Paul, Minnesota, USA.
- Farr, K.L.** 2003. *The forests of Canada*. Natural Resources Canada, Canadian Forest Service, Ottawa, Ontario.
- Forget, E., Nolet, P., Doyon, F., Delagrange, S., and Jardon, Y.** 2007. Ten-year response of northern hardwood stands to commercial selection cutting in southern Quebec, Canada. *Forest Ecology and Management* **242**(2-3): 764–775.
- Fortin, M., Guillemette, F., and Bédard, S.** 2009. Predicting volumes by log grades in standing sugar maple and yellow birch trees in southern Quebec, Canada. *Canadian Journal of Forest Research* **39**(10): 1928–1938.
- Fournier, A., Woods, M., Stinson, A., and Zhang, T.** 2006. *Maximizing the value of hardwoods through intensive silviculture (Stroke's Study)*. FPInnovations General Revenue Report Project No. 652. FPInnovations, Ste-Foy, Quebec, Canada.
- Gevorkiantz, S.R., and Duerr, W.A.** 1937. A yield table for northern hardwoods in the Lake States. *Journal of Forestry* **35**(4): 340–343.
- Godman, R.M.** 1957. *Silvicultural characteristics of sugar maple (Acer saccharum)*. Research Paper 50, USDA Forest Service, Lake States Forest Experiment Station, St. Paul, Minnesota, USA.
- Godman, R.M., Yawney, H.W., and Tubbs, C.H.** 1990. *Acer saccharum* Marsh. Sugar maple. Pages 325–332 in R.M. Burns and B.H. Honkala, technical coordinators. *Silvics of North America: Volume 2. Hardwoods*. USDA Forest Service Agricultural Handbook 654. USDA, Washington, D.C., USA.
- Gronewold, C.A., D'Amato, A.W., and Palik, B.J.** 2010. The influence of cutting cycle and stocking level on the structure and composition of managed old-growth northern hardwoods. *Forest Ecology and Management* **259**(6): 1151–1160.
- Gronewold, C.A., D'Amato, A.W., and Palik, B.J.** 2012. Relationships between growth, quality, and stocking within managed old-growth northern hardwoods. *Canadian Journal of Forest Research* **42**(6): 1115–1125.
- Guillemette, F., Bédard, S., and Fortin, M.** 2008. Evaluation of a tree classification system in relation to mortality risk in Quebec northern hardwoods. *The Forestry Chronicle* **84**(6): 886–899.
- Guillemette, F., Lambert, M.-C., and Bédard, S.** 2012. Sampling design and precision of basal area growth and stand structure in uneven-aged northern hardwoods. *The Forestry Chronicle* **88**(1): 30–39.

- Hartmann, H., Beaudet, M., Mazerole, M.J., and Messier, C.** 2009. Sugar maple (*Acer saccharum* Marsh,) growth is influenced by close conspecifics and skid trail proximity following selection harvest. *Forest Ecology and Management* **258**(5): 823–831.
- Hornbeck, J.W., and Leak, W.B.** 1992. *Ecology and management of northern hardwood forests in New England*. General Technical Report NE-159. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Horsley, S.B., Long, R.P. Long, Bailey, S.W., Hallett, R.A., and Hall, T.J.** 2000. Factors associated with the decline disease of sugar maple on the Allegheny plateau. *Canadian Journal of Forest Research* **30**(9): 1365–1378.
- Horsley, S.B., Long, R.P., Bailey, S.W, Hallett, R.A., and Wargo, P.M.** 2002. Health of eastern North American sugar maple forests and factors affecting decline. *Northern Journal of Applied Forestry* **19**(1): 34–44.
- Johnson, J.E., Miller, G.W., Baumgras, J.E., and West, C.D.** 1998. Assessment of residual stand quality and regeneration following shelterwood cutting in Central Appalachian hardwoods. *Northern Journal of Applied Forestry* **15**(4): 203–210.
- Jones, R.H., Nyland, R.D., and Raynal, D.J.** 1989. Response of American beech regeneration to selection cutting of northern hardwoods in New York. *Northern Journal of Applied Forestry* **6**(1): 34–36.
- Jones, T.A., and Thomas, S.C.** 1994. The time course of diameter increment responses to selection harvests in *Acer saccharum*. *Canadian Journal of Forest Research* **34**(7): 1525–1533.
- Juice, S.M., Fahey, T.J., Siccama, T.G., Driscoll, C.T., Denny, E.G., Eagar, C., Cleavitt, N.L., Minocha, R., and Richardson, D.A.** 2006. Response of sugar maple to calcium addition to northern hardwood forest. *Ecology* **87**(5): 1267–1280.
- Kenefic, L.S., and Nyland, R.D.** 2007. Cavity trees, snags, and selection cutting: a northern hardwood case study. *Northern Journal of Applied Forestry* **24**(3): 192–197.
- Kenefic, L.S., and Nyland, R.D., editors.** 2006. *Proceedings of the conference on diameter-limit cutting in northeastern forests*. General Technical Report NE-342. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Keys, K., and McGrath, T.** 2002. *Tree grade versus product output from a mature sugar maple stand in Cape Breton, Nova Scotia*. Forest Research Report No. 68. Nova Scotia Department of Natural Resources, Truro, Nova Scotia, Canada.
- La Rocque, G.** 1985. *Regeneration in a tolerant hardwood stand managed under single-tree selection*. Information Report PI-X-50. Natural Resources Canada, Canadian Forest Service - Petawawa National Forestry Institute, Chalk River, Ontario, Canada.
- Leak, W.B.** 1999. Species composition and structure of a northern hardwood stand after 61 years of group/patch selection. *Northern Journal of Applied Forestry* **16**(3): 150–153.

- Leak, W.B.** 2004. Diameter growth in even- and uneven-aged northern hardwoods in New Hampshire under partial cutting. *Northern Journal of Applied Forestry* **21**(3): 160–163.
- Leak, W.B., and Filip, S.M.** 1977. Thirty-eight years of group selection in New England hardwoods. *Journal of Forestry* **75**(10): 641–643.
- Leak, W.B., and Gove, J.H.** 2008. Growth of northern hardwoods in New England: a 25-year update. *Northern Journal of Applied Forestry* **25**(2): 103–105.
- Leak, W.B., and Sendak, P.E.** 2002. Changes in species, grade, and structure over 48 years in a managed New England northern hardwood stand. *Northern Journal of Applied Forestry* **9**(1): 25–27.
- Leak, W.B., Solomon, D.S., and DeBald, P.S.** 1987. *Silvicultural guide for northern hardwood types in the Northeast (revised)*. Research Paper NE-603. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Leak, W.B., and Yamasaki, M.** 2010. *Seventy-year record of changes in the composition of overstory species by elevation on the Bartlett Experimental Forest*. Research Paper NRS-13. USDA Forest Service, Northern Research Station, Newtown Square, Pennsylvania, USA.
- Lees, J.C.** 1978. *Hardwood silviculture and management: an interpretive literature review for the Canadian Maritime provinces*. Information Report M-X-93. Natural Resources Canada, Canadian Forest Service – Atlantic Forestry Centre, Fredericton, New Brunswick, Canada.
- Loucks, O.L.** 1962. A forest classification system for the Maritime provinces. *Proceedings of the Nova Scotian Institute of Science* **25**(2): 85–167.
- MacLean, D.W.** 1950. *Improvement cutting in tolerant hardwoods*. Silviculture Research Note 95. Canada Department Resources and Development, Forestry Branch, Forest Resources Division, Ottawa, Ontario, Canada.
- Magasi, L.P.** 1995. Forest insect pests in the Maritimes Region. Pages 11–26 in J.A. Armstrong and W.G.H. Ives. *Forest insect pests in Canada*. Natural Resources Canada, Canadian Forest Service, Science and Sustainable Development Directorate, Ottawa, Ontario, Canada.
- Magasi, L.P., and Hurley, J.E.** 1994. *Forest pest conditions in the Maritimes in 1993*. Information Report M-X-188E. Natural Resources Canada, Canadian Forest Service - Atlantic Forestry Centre, Fredericton, New Brunswick, Canada.
- McDonald, M.** 1999. *New Brunswick Crown Land hardwood veneer /sawlog quality survey*. New Brunswick Department of Natural Resources and Energy, Timber Management Branch. Fredericton, New Brunswick, Canada.
- Miller, G.W., Gottschalk, K.W., Graves, A.T., and Baumgras, J.E.** 2003. The effects of silvicultural thinning on tree grade distributions of five hardwood species in West Virginia. Pages 39–48 in B. Smalley, editor. 2001. *Proceedings of the 29th Annual Hardwood Symposium: Sustaining Natural Resources on Private Lands in the Central Hardwood Region*. National Hardwood Lumber Association, Memphis, Tennessee, USA.

- Miller, G.W., Graves, A.T., Gottschalk, K.W., and Baumgras, J.E.** 2008. Accuracy of tree grade projections for five Appalachian hardwood species. *Northern Journal of Applied Forestry* **25**(1): 45–51.
- Monger, N.R.** 2007. *Classification des tiges d'essences feuillues : normes techniques*. Québec Ministère des Ressources naturelles, de la Faune et des Parcs, Ste.-Foy, Quebec, Canada.
- Mulliens, E.J., and McKnight, T.S.** 1981. *Canadian woods: their properties and uses*. Third edition. University of Toronto Press, Toronto, Ontario, Canada.
- Myers, J.R., Miller, G.W., Wiant, H.V. Jr., and Barnard, J.E.** 1986. *Butt-log grade distributions for five Appalachian hardwood species*. Research Report NE-590. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Myren, D.T., editor.** 1994. *Tree diseases of eastern Canada*. Natural Resources Canada, Canadian Forest Service, Science and Sustainable Development Directorate, Ottawa, Ontario, Canada.
- Nelson, A.S., and Wagner, R.G.** 2011. Improving the composition of beech-dominated northern hardwood understories in northern Maine. *Northern Journal of Applied Forestry* **28**(4): 186–193.
- Niese, J. N., Strong, T., and Erdmann, G.G.** 1995. Forty years of alternative management practices in second-growth, pole size northern hardwoods. II. Economic evaluation. *Canadian Journal of Forest Research* **25**(7): 1180–1188.
- Nolet, P.D., Bouffard, A.L., Bohn, K.K., and Delagrange, S.** 2008. Relationship between canopy disturbance history and current density of *Fagus grandifolia* and *Acer saccharum* in a northern hardwood landscape. *Canadian Journal of Forest Research* **38**(2): 216–225.
- Norfolk, C.** 2004. *Staman 5.5 User's guide supplement*. New Brunswick Growth and Yield Unit, c/o New Brunswick Department of Natural Resources, Timber Management Branch, Fredericton, New Brunswick, Canada.
- Nyland, R.D.** 1987. Selection system and its application to uneven-aged northern hardwoods. Pages 49– 80 in R.D. Nyland. *Managing northern hardwoods, Proceedings of a Silviculture Symposium*. State University of New York, Syracuse, New York, USA.
- Nyland, R.D.** 1994. Careful logging in northern hardwoods. Pages 29–51 in J.A. Rice, editor. *Logging damage: the problems and practical solutions*. Forest Research Information Paper No. 117. Ontario Ministry of Natural Resources, Sault St. Marie, Ontario, Canada.
- Nyland, R.D.** 1996. *Silviculture: concepts and applications*. McGraw-Hill, Boston, Massachusetts, USA.
- Nyland, R.D.** 2003. Rehabilitating stands after diameter-limit cutting. In M. Béland, editor. *Proceedings of the tolerant hardwoods management conference*. Université de Moncton-Campus d'Edmundston, 8 May 2003, Edmundston, New Brunswick, Canada. [CD rom].
- Nyland, R.D.** 2006. Rehabilitating cutover stands: some ideas to ponder. Pages 47–51 in L.S. Kenefic and R.D. Nyland, editors. *Proceedings of the conference on diameter-limit cutting in northeastern forests*. General Technical Report NE-342. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.

- Nyland, R.D., Bashant, A.L., Bohn, K.K., and Verostek, J.M.** 2004. Interference to hardwood regeneration in northeastern North America: ecological characteristic of American beech, striped maple, and hobblebush. *Northern Journal of Applied Forestry* **23**(1): 53–61.
- Nyland, R.D., Bashant, A.L., Bohn, K.K., and Verostek, J.M.** 2006. Interference to hardwood regeneration in northeastern North America: controlling effects of American beech, striped maple, and hobblebush. *Northern Journal of Applied Forestry* **23**(2): 122–132.
- Ontario Ministry of Natural Resources (OMNR).** 1983. *Management of tolerant hardwoods in the Algonquin Provincial Park*. Ontario Ministry of Natural Resources, Toronto, Ontario, Canada.
- Ouellet, D., and Fournier, F.** 2009. *Research initiative for improving the competitiveness of the hardwood industry*. CWFC Fibre Facts 005. Natural Resources Canada, Canadian Forest Service - Canadian Wood Fibre Centre. Ottawa, Ontario, Canada.
- Patterson, S.L., Zak, D.R., Burton, A.J., Talhelm, A.F., and Pregitzer, K.S.** 2012. Simulated N deposition negatively impacts sugar maple regeneration in a northern hardwood ecosystem. *Journal of Applied Ecology* **49**(1): 155–163.
- Plonski, W.L.** 1974. *Normal yield tables (metric) for major forest species of Ontario*. Ontario Ministry of Natural Resources, Division of Forests, Toronto, Ontario, Canada.
- Roberge, M.R.** 1975. Effect of thinning on the production of high-quality wood in a Quebec northern hardwood stand. *Canadian Journal of Forest Research* **5**(1): 139–145.
- Roberge, M.R.** 1987. *Aménagement d'une bétulaie jaune à érables par la coupe par groupes : résultats de 15 ans*. (Management of a yellow birch-maple stand by cutting in groups: 15-year results). Information Report LAU-X-72. Natural Resources Canada, Canadian Forest Service – Laurentian Forestry Centre, Quebec, Quebec, Canada.
- Roberge, M.R.** 1988a. *Évolution d'une érablière à bouleau jaune soumise à différents traitements en 1966*. (Development of sugar maple-yellow birch stand following various treatments in 1966). Information Report LAU-X-82B. Natural Resources Canada, Canadian Forest Service – Laurentian Forestry Centre, Quebec, Quebec, Canada.
- Roberge, M.R.** 1988b. *Vingt ans d'aménagement par groupes d'une bétulaie jaune à érables*. (Twenty years of group management in a yellow birch-sugar maple stand). Information Report LAU-X-81B. Natural Resources Canada, Canadian Forest Service – Laurentian Forestry Centre, Quebec, Quebec, Canada.
- Robertson, S., and Myketa, D.** 1998. *The selection silvicultural system as related to vegetation management*. Northwest Science and Technology Note TN-44. Ontario Ministry of Natural Resources, Thunder Bay, Ontario, Canada.
- Rowe, J.S.** 1972. *Forest regions of Canada*. Publication No. 1300. Natural Resources Canada, Canadian Forest Service, Ottawa, Ontario, Canada.

- Sendak, P.E., and Leak, W.B.** 2000. Hardwood quality development in the White Mountains of New Hampshire. *Northern Journal of Applied Forestry* **17**(1): 9–19.
- Simpson, R., and Coy, D.** 1999. *An ecological atlas of forest insect defoliation in Canada, 1980–1996*. Information Report M-X-206E. Natural Resources Canada, Canadian Forest Service – Atlantic Forestry Centre, Fredericton, New Brunswick, Canada.
- Smallridge P., and Nyland, R.D.** 2009. *Woodland guidelines for the control and management of American beech*. Forest Connect Fact Sheet Series. Cornell University Cooperative Extension, Ithaca, New York, USA.
- Smith, D.M.** 1986. *The practice of silviculture*. Eighth edition. John Wiley & Sons Inc., New York, New York, USA.
- Solomon, D.S.** 1977. *The influence of stand density and structure on the growth of northern hardwoods in New England*. Research Paper NE-362. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Strong, T.F., Erdmann, G.G., and Niese, J.N.** 1995. Forty years of alternative management practices in second-growth, pole size northern hardwoods. I. Tree quality development. *Canadian Journal of Forest Research* **25**(7): 1173–1179.
- Trimble, G.R. Jr.** 1968. *Growth of Appalachian hardwoods as affected by site and residual stand density*. Research Paper NE-98. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Tubbs, C.H.** 1965. *Influence of temperature and early spring conditions on sugar maple and yellow birch germination in upper Michigan*. Research Note LS-72. USDA Forest Service, Lake States Forest Experiment Station, St. Paul, Minnesota, USA.
- Tubbs, C.H., and Houston, D.R.** 1990. *Fagus grandifolia* Ehrh. American beech. Pages 325–332 in R.M. Burns and B.H. Honkala, technical coordinators. *Silvics of North America: Volume 2. Hardwoods*. USDA Forest Service Agricultural Handbook 654. USDA, Washington, D.C., USA.

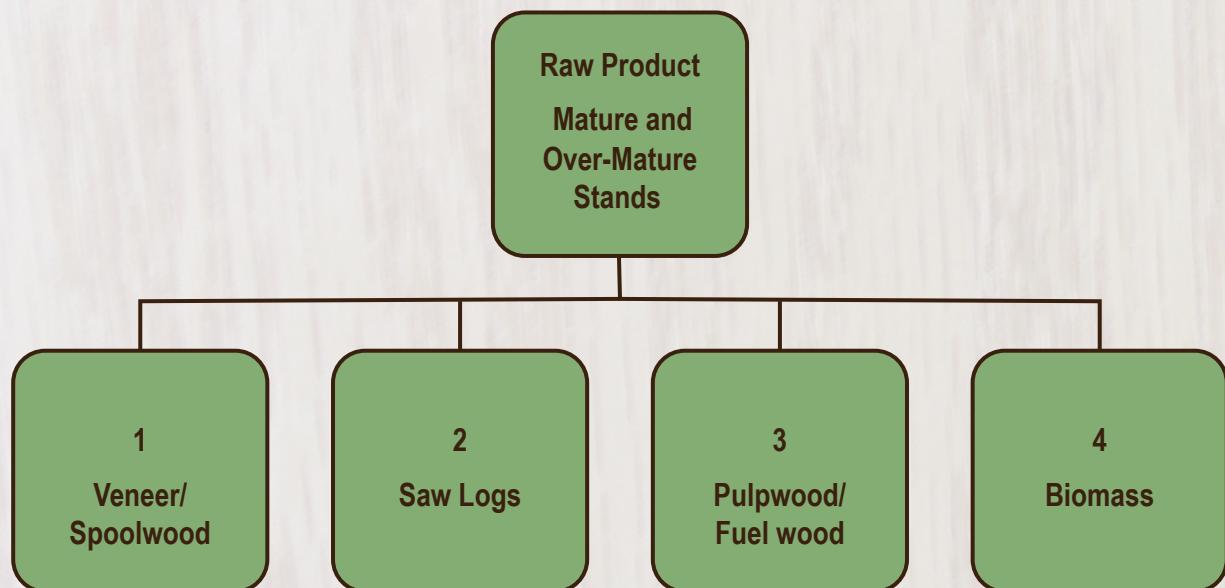
- Tubbs, C.H., and Reid, B.D.** 1984. Logging season affects hardwood reproduction. *Northern Journal of Applied Forestry* **1**(1): 5–7.
- Vanderwel, M.C., Thorpe, H.C., Shuter, J.L., Caspersen, J.P., and Thomas, S.C.** 2008. Contrasting down woody debris dynamics in managed and unmanaged northern hardwood stands. *Canadian Journal of Forest Research* **38**(11): 2850–2861.
- Webster, C.E., Reed, D.D., Orr, B.D., Schmierer, J.M., and Pickens, J.B.** 2009. Expected rates of value growth for individual sugar maple crop trees in the Great Lakes Region. *Northern Journal of Applied Forestry* **26**(4): 133–140.
- Wiedenbeck, J., Wieman, M., Alderman, D., Baumgras, J., and Luppold, W.** 2004. *Defining hardwood veneer log quality attributes*. General Technical Report NE-313. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Wink, R.A., and Allen, D.C.** 2007. The combined effects of forest tent caterpillar defoliation and timber stand improvement activity on epicormic sprouting of sugar maple and black cherry. *Northern Journal of Applied Forestry* **25**(2): 61–65.
- Wood, D., Yanai, R., Allen, D., and Wilmot, S.** 2009. Sugar maple decline after defoliation by forest tent caterpillar. *Journal of Forestry* **107**(1): 29–37.
- Yaussy, D.M.** 1993. *Method for estimating potential tree-grade distributions for northeastern forest species*. Research Paper NE-670. USDA Forest Service, Northeastern Forest Experiment Station, Newtown Square, Pennsylvania, USA.
- Zelazny, V.F., general editor.** 2007. *Our landscape heritage: the story of ecological land classification in New Brunswick*. Second edition. New Brunswick Department of Natural Resources, Fredericton, New Brunswick, Canada.

Appendix I

Modified NBDNR Tree Product Grading System

(After McDonald (1999))

- | | |
|-----------------------|--|
| 1. Veneer | <ul style="list-style-type: none">- 2.5 m out of the first 4 m of tree- clear on all four faces of tree stem- no major defects- dbh >24 cm |
| Spoolwood | <ul style="list-style-type: none">- white birch and white ash- 2.5 m out of the first 4 m of tree- clear on all four faces of tree stem- no more than two minor defects- dbh >16 cm |
| 2. Saw logs | <ul style="list-style-type: none">- 2.5 m out of the first 4 m of tree- clear on all three faces of tree stem- no more than two minor defects on three clear faces- dbh >24 cm |
| 3. Pulpwood /Fuelwood | <ul style="list-style-type: none">- trees that do not meet criteria 1 and 2- trees with 50% or more merchantable volume |
| 4. Biomass | <ul style="list-style-type: none">- trees that do not meet criteria 1, 2, and 3- trees with less than 50% merchantable volume |



Appendix II

Staff

FPInnovations – Wood Products

Manager, Lumber Manufacturing Department - Francis Fournier

Lumber Manufacturing Department, Senior Technologists:

Luc Bédard

Yves Giroux

Ghislain Veilleux

Resource Characterization, Senior Technologist:

Francis Tanguay

Canadian Wood Fibre Centre

Regional Coordinator - Dean Toole

Research Scientist - Chhun-Huor Ung

Research Scientist, Resource Characterization - Isabelle Duchesne

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Tyler Harrison

Brian Williams

Summer Research Assistants:

Sarah McMullin

Adam Schaubel

Katherine Standen

The Canadian Wood Fibre Centre brings together forest sector researchers to develop solutions for the Canadian forest sector's wood fibre related industries in an environmentally responsible manner. Its mission is to create innovative knowledge to expand the economic opportunities for the forest sector to benefit from Canadian wood fibre. The Canadian Wood Fibre Centre operates within the CFS, but under the umbrella of FPIInnovations' Board of Directors.

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Additional information on Natural Resources Canada, the Canadian Forest Service, and Canadian Wood Fibre Centre research and publications is also available online at: <http://cwfc.nrcan.gc.ca>. To download or order additional copies of this publication, see our online bookstore at: <http://bookstore.cfs.nrcan.gc.ca>.

Le Centre canadien sur la fibre de bois réunit des chercheurs du secteur forestier afin d'élaborer des solutions responsables sur le plan environnemental pour les industries forestières du secteur de la fibre de bois du Canada. Sa mission est de produire des connaissances innovatrices qui accroîtront les débouchés économiques pour que le secteur forestier puisse tirer profit des fibres ligneuses canadiennes. Le Centre canadien sur la fibre de bois fonctionne au sein du Service canadien des forêts, mais sous l'égide du conseil d'administration de FPIInnovations.

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