FORÊTS, FAUNE ET PARCS

MULTI-AGED SILVICULTURE
of northern hardwood and mixedwood forests

Proceedings

Field tour in Québec – August 24–26, 2016

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Québec

MULTI-AGED SILVICULTURE
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Field tour in Québec – August 24–26, 2016

Hosted by the *ministère des Forêts, de la Faune et des Parcs du Québec* (MFFP)
and the NESAF Silviculture Working Group

Sponsored by the New England Society of American Foresters

Note to readers:

The contents of these abstracts are the sole responsibility of the authors and do not necessary reflect the position of the *Ministère des Forêts, de la Faune et des Parcs.*

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Welcome to Québec!

We are pleased to welcome you on this tour of the main forest types of southern Québec's northern hardwood and temperate mixedwood forests. During 3 days, you will see various aspects of uneven-aged, irregular, and even-aged management in the Duchesnay Forest, Portneuf County, and the *Réserve faunique du Saint-Maurice*. Researchers from the *Direction de la recherche forestière* (DRF) will present their most recent findings on hardwood and mixedwood silviculture. We hope that you will have enriching cross-border discussions and that you will enjoy your visit in *La Belle Province*.

Have a great tour!

The 2016 NESAF Tour organizing committee:

- **Patricia Raymond**, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
- **Steve Bédard**, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
- **Anthony D'Amato**, University of Vermont
- **Bennet Leon**, Vermont Agency of Natural Resources
- **Nancy Patch**, Vermont Department of Forests, Parks and Recreation

Acknowledgements

We would like to thank the presenters and everyone who helped organize this tour and edit the proceedings. We address special thanks to Catherine Larouche and Jean-Pierre Saucier for their support of the event and to Eric Saulnier and Daniel Dumais for their assistance in organizing the mixedwood tour. Publication of these proceedings would not have been possible without the contributions of Maripierre Jalbert for graphic design, Denise Tousignant and Nathalie Langlois for editing and layout, as well as Jean Noël and Véronique Poirier for map production.

Patricia Raymond

Map of the *Station touristique Duchesnay*

Legend

- Auberge and Lodges
- Cabins
- Service pavilions
- Partners
- Other Buildings

- Principal Trail
- Secondary Trail
- Snowmobile Access Trail
- Bike Path Snowmobile Trail

- Lodging
- Swimming
- Bike Rental
- Climbing Wall
- Volleyball
- Treetop Adventures
- Hiking
- Boat Rental

- Ice Fishing
- Skating Rink
- Cross-country Skiing
- Snowshoeing
- Tube Slide
- Snowmobile Rental
- Dog Sledding
- Archery
- Games

- Meeting and Reception Halls
- Jacuzzi
- Exercise Room
- Spa and Massage
- Picnic Tables
- Snack Bar
- Restaurant
- Bar
- First Aid

- Parking
- Bike Parking
- Snowmobile Parking

Figure 1. Map of the *Station touristique Duchesnay*. NESAF Tour participants reside in the Caribou Lodge.

Tour overview

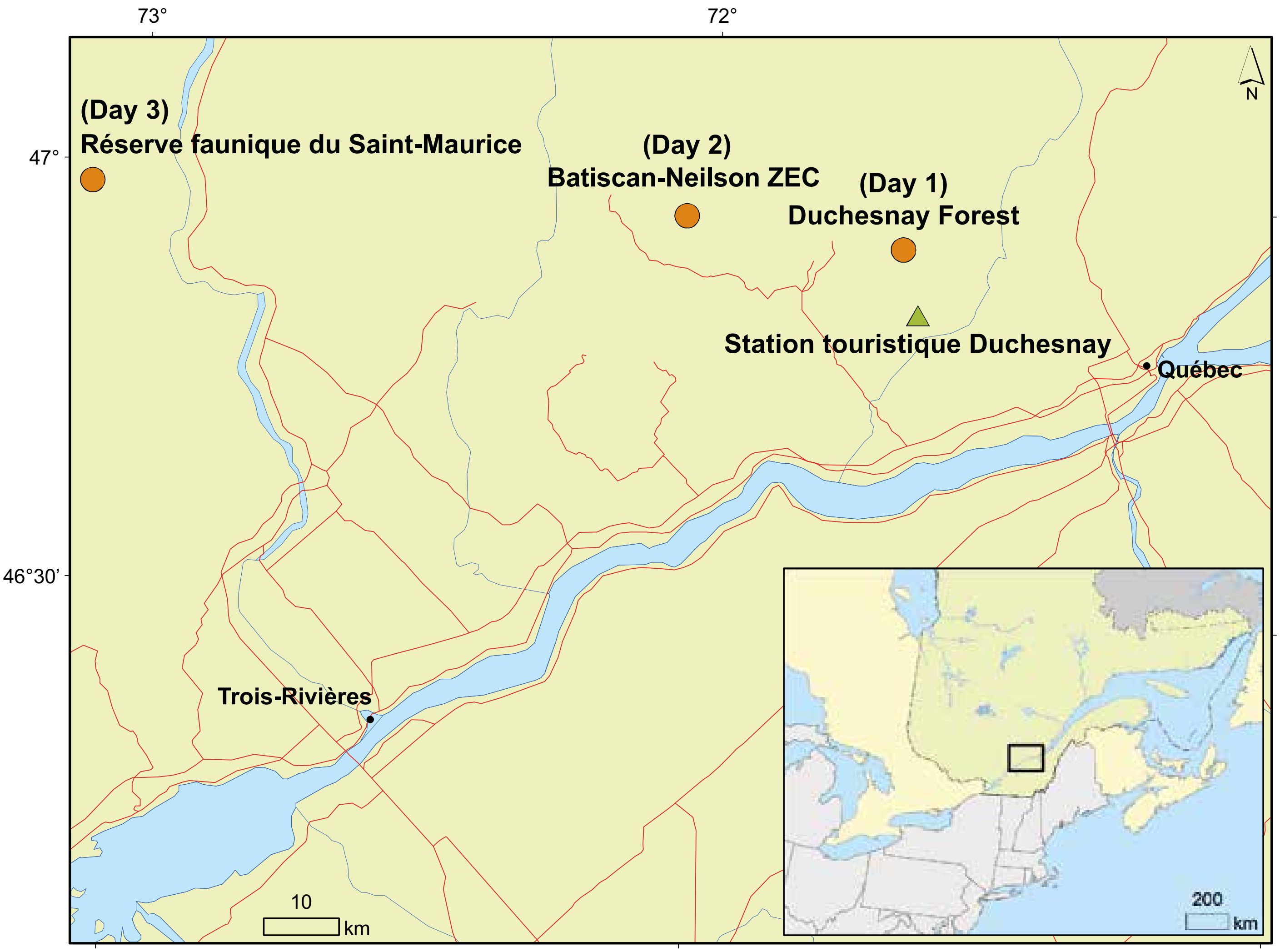

Figure 2. General map of the tour.

Tour schedule

Day 1. August 24, 2016: Duchesnay Forest – Northern hardwood silviculture

11:30–13:00	Arrival and check-in at the *Station touristique Duchesnay* reception desk (*Auberge*) Optional lunch at the resort's restaurant (*Auberge*)
13:00–13:30	Drive to experimental sites
13:30–13:45	***Introduction to hardwood forest ecology, exploitation and silviculture in Québec*** (presented by Steve Bédard)
13:30–14:45	**Stop 1.** Irregular shelterwood system (presented by Steve Bédard) ***Irregular shelterwood cutting as an adapted silvicultural practice and tool to rehabilitate impoverished hardwood stands***
15:15–15:30	Break
15:30–16:15	**Stop 2.** Commercial thinning (presented by François Guillemette) ***Rehabilitation using even-aged management in a "degraded" stand***
16:15–17:00	**Stop 3.** Selection cutting (presented by Steve Bédard) ***Rehabilitation of uneven-aged northern hardwood stands using the selection system***
17:00–17:30	**Stop 4.** Yellow birch regeneration in small groups (presented by Steve Bédard)
17:30–19:00	Wrap-up (presented by Anthony D'Amato) and happy hour ***Evolution of northern hardwood silviculture across North America: trends in application and current issues***
19:00	Dinner at the *Station touristique Duchesnay*

Patricia Raymond

Day 2. August 25, 2016: Portneuf County – Mixedwood silviculture

8:00–9:00	Drive to Batiscan-Neilson ZEC, Portneuf County
9:00–9:15	***Introduction to mixedwood management and silviculture in Québec*** (presented by Patricia Raymond)
9:15–9:45	**Stop 1.** Disturbance history (presented by Yan Boucher) ***Natural and anthropogenic disturbance regimes in the temperate mixedwood forest***
10:00–10:15	Break
10:15–11:45	**Stop 2.** Patch cutting (presented by Patricia Raymond) ***The SSAM Project: assessing a gap-based approach to maintain the composition and structure of yellow birch–conifer stands***
12:00–12:45	Lunch at Lake Tessier
13:00–14:30	**Stop 3.** Hybrid single-tree and group selection cutting (presented by Daniel Dumais and Patricia Raymond) ***Enrichment planting in small groups to sustain the red spruce component in yellow birch–conifer stands: the ecophysiological response***
14:45–15:00	Break
15:00–16:30	**Stop 4.** Irregular shelterwood cutting in mixed stands — Phase I (presented by Patricia Raymond) ***Irregular shelterwood as an alternative to clearcutting in balsam fir–yellow birch stands***
16:30–17:30	Drive to Duchesnay
18:30	Free time. Optional group dinner in Old Québec (details to come)

Day 3. August 26, 2016: Lower Saint-Maurice - Mixedwood silviculture (continued)

8:00–10:00	Drive to the *Réserve faunique du Saint-Maurice*
10:00–10:15	Break
10:15–11:45	**Stop 1.** Irregular shelterwood cutting in mixed stands — Phase II (presented by Patricia Raymond) ***Assessing the intermediate disturbance hypothesis with the irregular shelterwood system in yellow birch–conifer stands***
12:00-13:00	Wrap-up (presented by Laura Kenefic) and lunch at the Mattawin River ***Mixedwood management in the Northeastern United States***

List of vernacular and Latin names of trees, shrubs, animals, insects and pathogens mentioned in this document

Category	Vernacular name	Latin name
Trees	American beech	*Fagus grandifolia* Ehrh.
	Basswood	*Tilia americana* L
	Bitternut hickory	*Carya cordiformis* (Wangenh) K. Koch.
	Black ash	*Fraxinus nigra* Marsh.
	Black cherry	*Prunus serotina* Ehrh.
	Black spruce	*Picea mariana* (Mill.) B.S.P.
	Butternut	*Juglans cinerea* L.
	Eastern hemlock	*Tsuga canadiensis* (L.) Carr.
	Eastern hop-hornbeam	*Ostrya virginiana* (Mill.) K. Koch
	Eastern white cedar (Canada) or Northern white-cedar (U.S.A.)	*Thuja occidentalis* L.
	Eastern white pine	*Pinus strobus* L.
	Large-toothed aspen	*Populus grandidentata* Michaux
	Paper birch	*Betula papyrifera* Marsh.
	Red maple	*Acer rubrum* L.
	Red oak	*Quercus rubra* L.
	Red spruce	*Picea rubens* Sarg.
	Sugar maple	*Acer saccharum* Marsh.
	Trembling aspen	*Populus tremuloides* Michx.
	White ash	*Fraxinus americana* L.
	White elm	*Ulmus americana* L.
	White spruce	*Picea glauca* (Moench) Voss
	Yellow birch	*Betula alleghaniensis* Britton
Shrubs	Mooseberry	*Viburnum alnifolium* Marsh.
	Mountain maple	*Acer spicatum* Lam.
	Pin cherry	*Prunus pensylvanica* L.f.
	Striped maple	*Acer pensylvanicum* L.
Animals	American black bear	*Ursus americanus* Pallas
	Moose	*Alces alces* L.
	Red-backed salamander	*Plethodon cinereus* Green
	White-tailed deer	*Odocoileus virginianus* Zimm.
Insects and pathogens	Beech bark disease	*Neonectria faginata* (Lohman *et al.*) Castl
	Spruce budworm	*Choristoneura fumiferana* (Clem)

Day 1 — Duchesnay forest: Northern hardwood silviculture

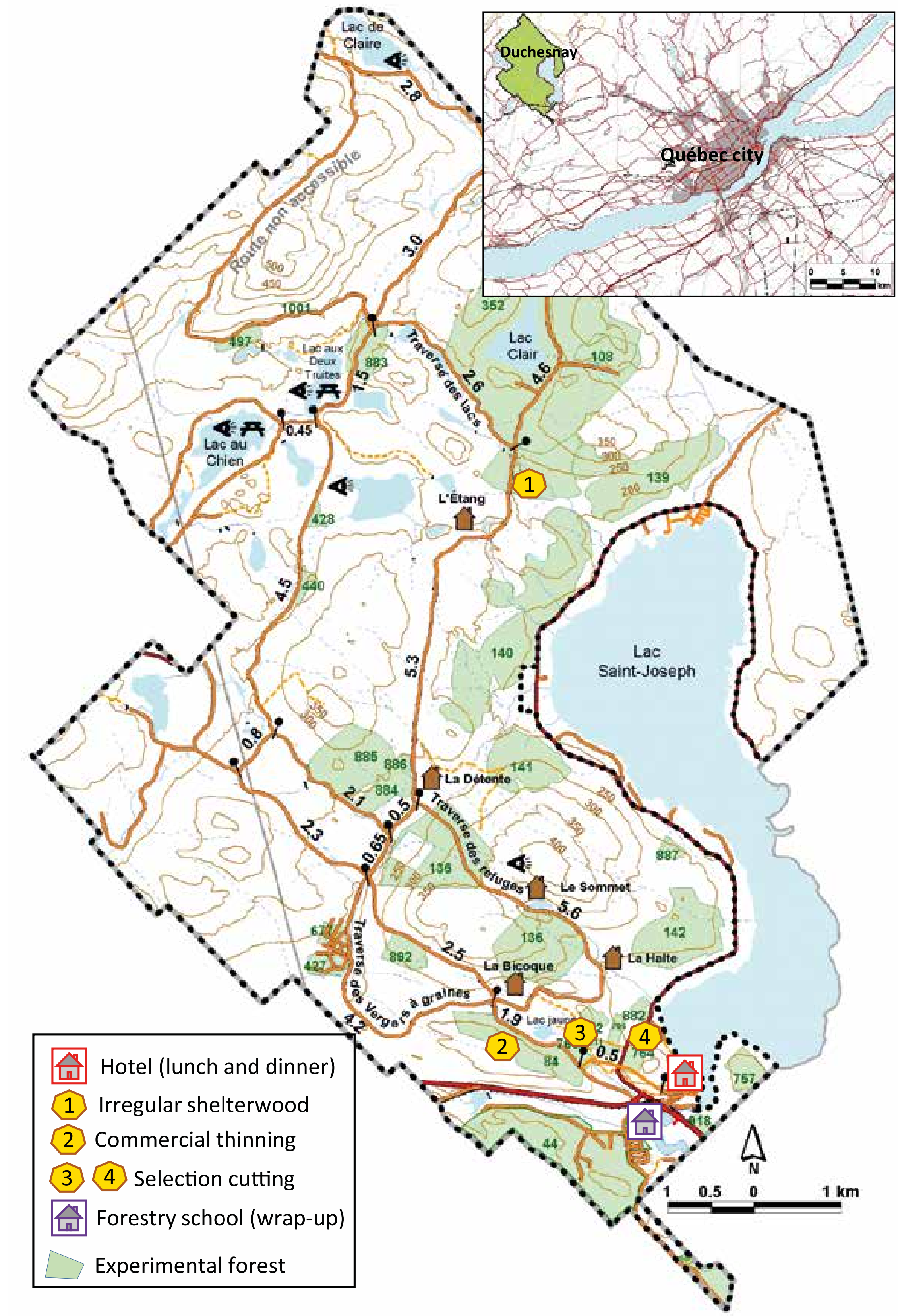

Figure 3. Map of the Duchesnay forest


Steve Bédard

Introduction to hardwood forest ecology, exploitation and silviculture in Québec

Steve Bédard, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs

The hardwood forest covers the southernmost part of Québec and occupies the northern portion of a wide band extending across east-central United States, where deciduous species predominate. It covers 7% of Québec's area, or almost 110 000 km^2. Maple stands predominate in the hardwood zone. Though they are dominated by sugar maple, they also contain other companion species such as bitternut hickory, butternut, white ash, basswood, eastern hop-hornbeam, black cherry, red oak, white elm, American beech, yellow birch and black ash, depending on the region or the site.

Québec's hardwood forests are found in three different bioclimatic domains: the sugar maple–hickory domain, at the extreme southwestern corner of the province, the sugar maple–basswood domain, a little further north and east, in the valley of the St. Lawrence and Gatineau rivers, and further north, the sugar maple–yellow birch domain, which makes up the northernmost part of the hardwood forest (Figure 4). It covers the southern portion of the Laurentian Plateau and the Appalachian hills. In these three domains, hardwood forests occur in various habitats, but not under extreme conditions such as very wet, very dry or extremely stony soils, which are mostly colonized by mixedwood and softwood stands. Very wet soils generally favor the development of stands composed of balsam fir, red maple, red spruce or white spruce, eastern white cedar and black spruce. Stands of yellow birch with balsam fir are often found on very stony soils on lower slopes in the sugar maple–yellow birch domain. Hemlock, eastern white pine and eastern white cedar often occur on escarpments.

Human colonisation left a heavy mark on the hardwood forest. Vast areas were cleared for agriculture, especially in the valley and along the tributaries of the St. Lawrence River. Large forest tracts were left on rolling and mountainous lands covered with sand and stone deposits that made them unsuitable for farming. Within farmed areas, some forested zones also remain with excessive soil moisture associated with organic soils and heavy clays, or on poor sands.

In the southernmost part of Québec, where soils are more fertile and the temperatures warmer, the sugar maple–hickory and sugar maple–basswood domains were the most affected by human activity. Clearings, fires, farming, and livestock rearing have fragmented the forest landscape. Toward the north, in the sugar maple–yellow birch and balsam fir–yellow birch domains, large forest tracts are more common, with mosaics of stands at various stages of development following fires or clearcuttings. In early stages, the forest is dominated by shade-intolerant species such as trembling aspen and large-toothed aspen.

From the beginning of 19th century to the end of the 20th century, forest exploitation in Québec was mainly driven by selective cutting of hardwoods and pines. At that time, the forest was seen as an endless resource. Until the mid-1990s, hardwood forests were commonly subject to diameter-limit cutting, which consists of removing merchantable trees above a certain specified diameter, determined by species and the desired end-use. Because the forest was close to inhabited areas, repeated partial cuts were often performed, in which the most valuable species (red oak, yellow birch, sugar maple and white pine) were systematically harvested. This often left standing trees of poorer quality, weakened stand potential and caused regeneration problems when the cut was too intense. As a result, hardwood stand quality decreased overall, ranging from good to depleted.

In the early 1980s, government authorities looked for solutions to this problem. Silvicultural systems based on natural stand dynamics, such as selection cutting, were proposed to ensure the sustained yield of uneven-aged stands that were still sufficiently stocked with quality trees. The shelterwood

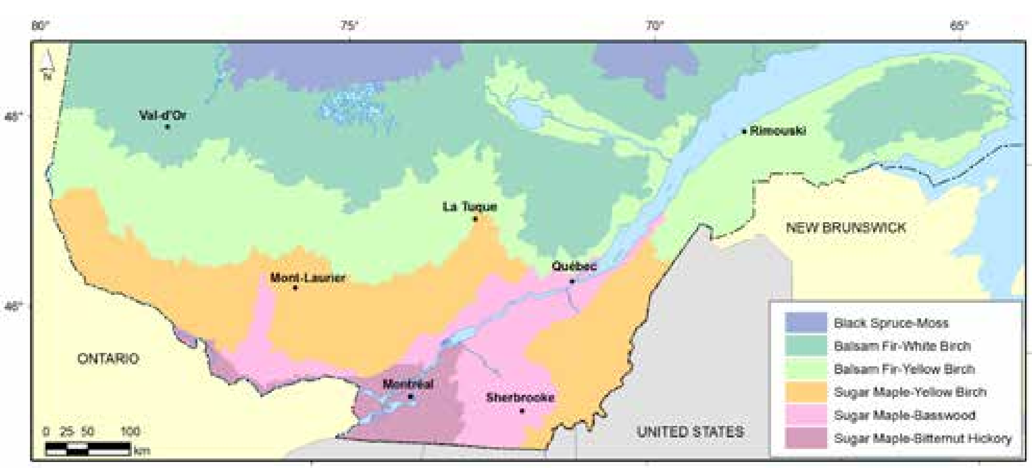

Figure 4. Map of Québec's bioclimatic domains.

and group/patch selection systems were also proposed to rehabilitate high-graded stands and to promote intermediate shade-tolerant species, respectively. More recently, the irregular shelterwood system was proposed to rehabilitate high-graded hardwood forests and to favor mixed-species stands. Most of these systems are tested and monitored by the *Direction de la recherche forestière* (Figure 5).

During this first day of the tour, you will see examples of experiments on selection cutting, irregular shelterwood and commercial thinning after a regeneration cut in a young even-aged stand.

This text can be cited as follows:

Bédard, S., 2016. Introduction to hardwood forest ecology, exploitation and silviculture in Québec. In: Ministère des Forêts, de la Faune et des Parcs (ed.), 2016. *Multi-aged silviculture of northern hardwood and mixedwood forests. Proceedings — Field tour in Québec.* Hosted by the ministère des Forêts, de la Faune et des Parcs and the New England Society of American Foresters Silviculture Working Group. August 24–26, 2016. Québec, QC, Canada. p. 9–10.

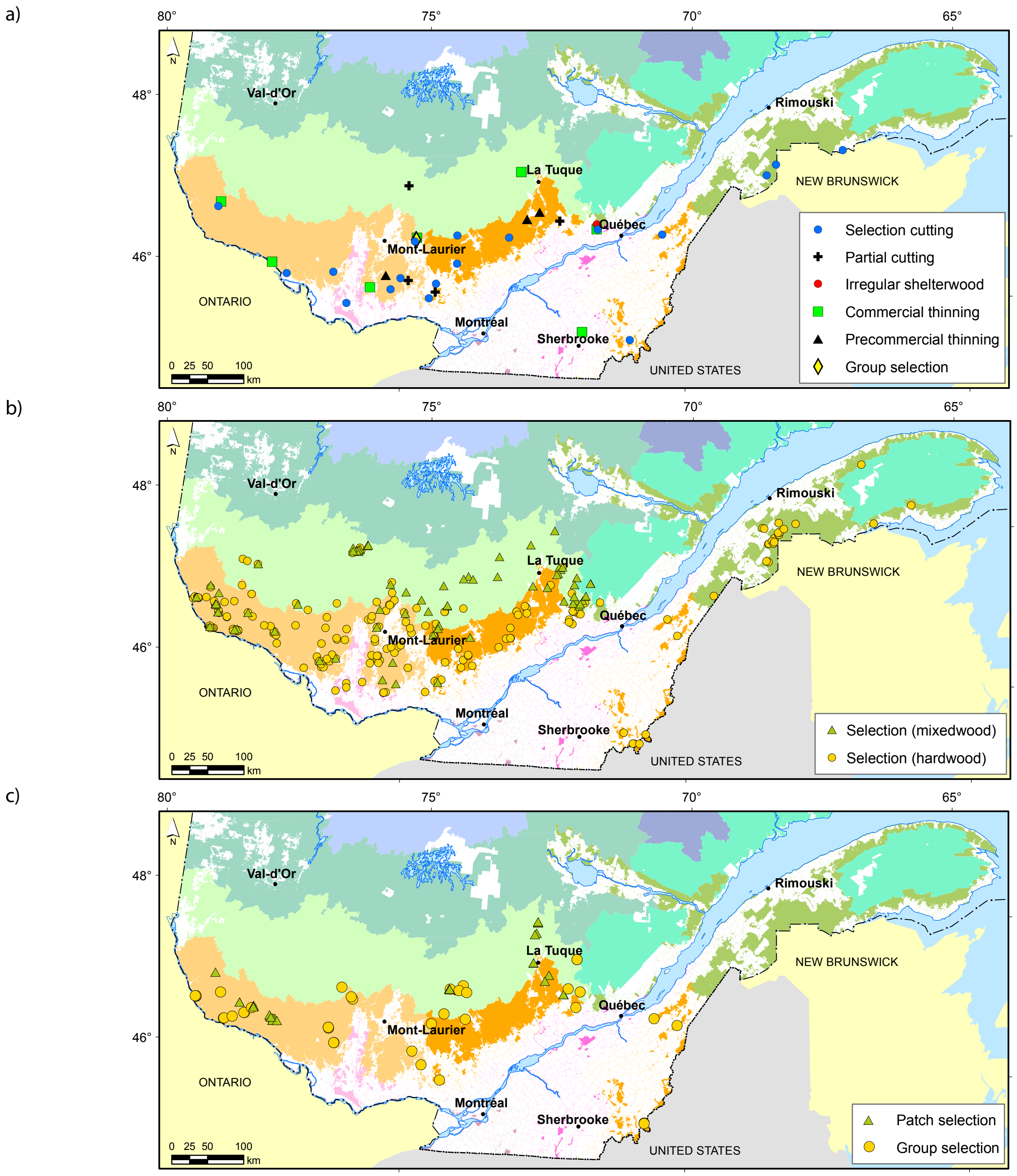

Figure 5. Location of DRF study sites: a) experimentation of different silvicultural systems, b) monitoring of operationally applied selection cuttings and c) monitoring of operationally applied group and patch selection cuttings.

Day 1, Stop 1: Irregular shelterwood system

Irregular shelterwood cutting as an adapted silvicultural practice and tool to rehabilitate impoverished hardwood stands

Steve Bédard, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
Collaborators: François Guillemette, Patricia Raymond, Stéphane Tremblay, Catherine Larouche and Josianne DeBlois

Context

In the past, sugar maple–yellow birch stands and yellow birch stands were mostly exploited by selective cuttings. These practices have reduced stand quality and often left stands with an irregular structure and an insufficient regeneration of desired species. We now face the challenge of bringing these stands into production, though they are composed of species with different autecologies. To do this, we must improve their composition, quality and structure, while observing Québec's guidelines regarding ecosystem-based management and prohibiting the use of herbicides.

Objectives

This project studies stand dynamics after single-tree cuttings, group selection cuttings and various types of irregular shelterwood cuttings. More specifically, it aims to evaluate the impact of cutting treatments on growth, yield and wood value; conservation of old growth forest attributes; stand composition and stem quality; regeneration and competing vegetation; microclimatic conditions; plant diversity. It also examines how beech bark disease and browsing by cervids affect regeneration.

Study details

The experiment was initiated in 2009 in a sugar maple–yellow birch stand of the Duchesnay forest station, near Québec City. The design includes 5 treatments:

- **Control** (no intervention);
- **SC**: single-tree and group selection cutting;
- **CCIS-14** and **CCIS-16**: continuous cover irregular shelterwood with a residual basal area of 14 or 16 m^2/ha, respectively;
- **EIS**: extended irregular shelterwood.

Treatments are replicated 4 times (4 blocks), for a total of 20 experimental units (110 m × 110 m).

For the SC treatment, we used a target diameter distribution (DBq approach) with a target basal area of 18 m^2/ha, a *q* factor of 1.12 (2 cm-class dbh distribution) for pole-size trees, and a *q* factor of 1.09 for larger trees. For the CCIS-14 and CCIS-16 treatments, we removed unacceptable growing stock (UGS) instead of retaining a target diameter. Consequently, the residual stand structure was influenced by both the pre-harvest UGS distribution and the target residual basal area (14 or 16 m^2/ha). For the EIS treatment, trees were marked in order to leave a residual uniform crown cover of 50%, composed of the most vigorous seed trees.

Trees were cut in 2009 using a cut-to-length system (with a single grip harvester and a forwarder). Stems were felled and bucked on the felling area, then hauled using the forwarder. American beech saplings were removed using brush saws in group openings as well as across the entire area of EIS units. A site preparation (scarification) was also performed in the openings (SC, CCIS-16 and CCIS-18 treatments) and between the residual trees in the EIS units (Figure 6). A sample of 150 stems were bucked, classified, measured and sawn to estimate product recovery. In each experimental unit, the usual dendrometric variables were recorded, along with stem quality. Moreover, 36 quadrats were established per unit to survey regeneration and vegetation and to measure light using hemispherical photographs. Wildlife trees, snags and woody debris were surveyed and classified.

In 2011, 12 exclosures (10 m × 10 m) were installed in blocks I, II and III of the CCIS-14 and the EIS experimental units. Four regeneration plots were established under similar conditions inside and outside each exclosure.

Most variables were measured before cutting (2009), after cutting (2010) and after 5 years (2014). Regeneration was also measured 3 years after cutting (in 2012). Additional measurements are planned at 5-year intervals.

Preliminary results

Net growth and mortality (Figure 7):

- After 5 years, all the cutting treatments showed better net growth and less mortality than the control. However, mortality was greater than expected because of infection by beech bark disease.
- More than 60% of the mortality was composed of American beech in the control, SC and CCIS-16 treatments. American beech accounted for 40% of mortality in the CCIS-14 treatment and less than 20% in the EIS treatment.
- After 5 years, a high proportion of American beech survivors are infested by beech bark disease. We can expect high beech mortality in the years to come.

a)

b)

c)

Figure 6. Overview of the treatments: a) Control stand (no intervention), showing the abundance of American beech in the understory; b) small group cutting with site preparation in the continuous cover irregular shelterwood treatment (understory control of American beech and soil scarification); c) extended irregular shelterwood, showing the uniform residual cover and site preparation (control of understory American beech and soil scarification). Photos: François Guillemette.

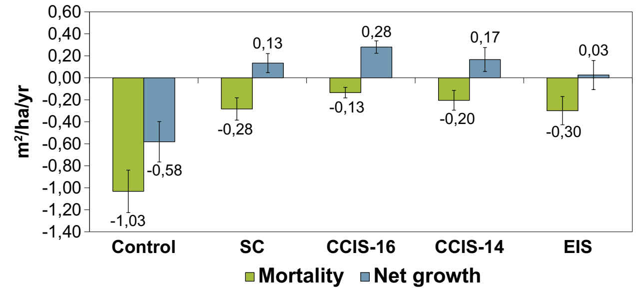

Figure 7. Net growth and total mortality after 5 years (2010–2014). Error bars represent standard error.

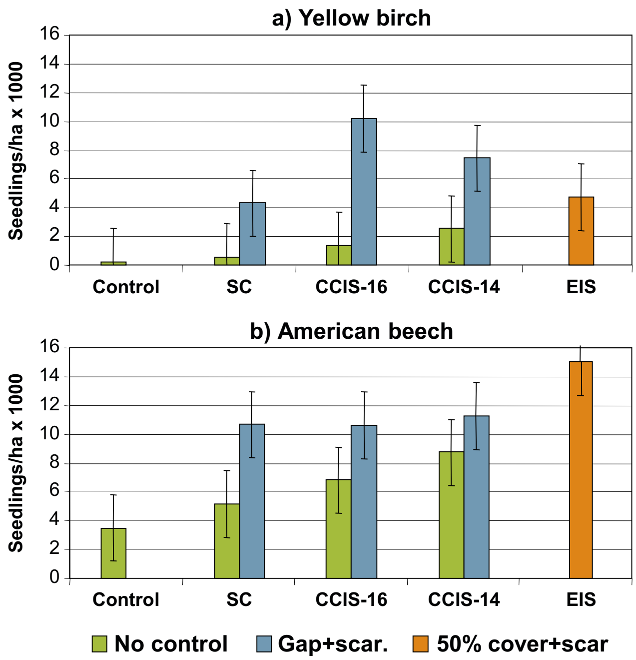

Figure 8. Yellow birch (a) and American beech (b) seedling density after 5 years (height 61–300 cm). For the SC and CCIS treatments, data was analysed separately inside (gap+scar.) and outside the gaps (no control). Error bars represent standard error.

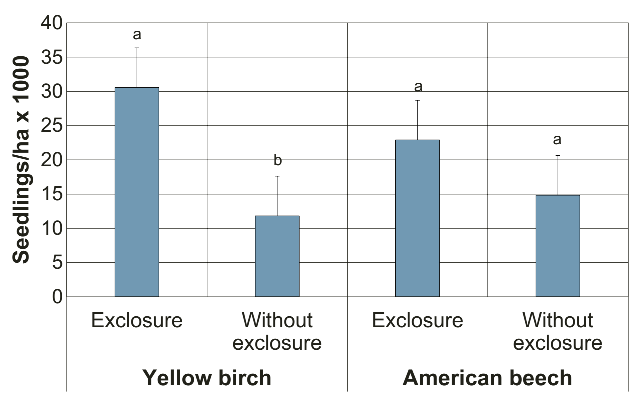

Figure 9. Four-year effects of cervid browsing on regeneration density of yellow birch and American beech (2011–2014, seedling height >101 cm). Error bars represent standard error.

Regeneration (Figures 8 and 9)

- Removal of American beech saplings (as an attempt to control this species), scarification and stand opening did favor yellow birch seedlings, but also resulted in abundant American beech stem sprouts. However, without exclosures, American beech still dominated the understory in the larger seedling height classes.
- Sugar maple regeneration was also favored by the treatments, but remained in the smallest seedlings height classes. With its acidic soils and poor calcium content, the study site is not favorable to this species.
- Mechanical control of American beech was not as efficient as expected, due to cervid browsing of yellow birch and the abundance of American beech sprouts.

References

Bédard, S., F. Guillemette, P. Raymond, S. Tremblay, C. Larouche and J. Deblois, 2014. Rehabilitation of northern hardwood stands using multi-cohort systems in Quebec. J. For. 112(3): 276–286.

Bédard, S., 2015. Experimentation of silvicultural treatments in northern hardwood stands affected by beech bark disease with an abundant beech understory. Beech bark disease best management practices workshop. Huntsville, ON. September 29, 2015. 17 p. [presentation].

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Bédard, S., F. Guillemette, P. Raymond, S. Tremblay, C. Larouche and J. DeBlois, 2016. Irregular shelterwood cutting as an adapted silvicultural practice and tool to rehabilitate impoverished hardwood stands. In: Ministère des Forêts, de la Faune et des Parcs (ed.), 2016. *Multi-aged silviculture of northern hardwood and mixedwood forests. Proceedings — Field tour in Québec.* Hosted by the ministère des Forêts, de la Faune et des Parcs and the New England Society of American Foresters Silviculture Working Group. August 24–26, 2016. Québec, QC, Canada. p. 11–13.

Day 1, Stop 2: Commercial thinning

Rehabilitation using even-aged management in a "degraded" stand

François Guillemette, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
Collaborators: Sébastien Meunier, Steve Bédard and Pierre Laurent

Background

In the summer of **1971,** a complete clearcut (any tree >30 cm in height) was done in a 58-ha sugar maple–American beech–yellow birch stand that was considered "degraded". Initial basal area (BA) was 23 m²/ha (100 ft²/ac) and commercial volume was 189 m³/ha. Composition was 55% sugar maple (SM), 21% American beech (AB) and 16% yellow birch (YB). There were 1 320 saplings/ha: 40% AB, 32% SM and 9% YB. Of the 88 400 seedlings/ha, 83% were SM.

In May **1982** (age 10), total natural regeneration was over 20 000 stems/ha including 5 300 YB. An experiment began with plots dispersed over 17.2 ha (5 blocs, 48 plots of 0.1 ha each) to study the effects of crop tree thinning (bole thinning with a radius of 0, 0.5, 1.0, and 1.5 m) and fertilization (NPK, N). The best YB were selected with a 5-m spacing (400 trees/ha).

In the summer of **1988** (age 16), a pruning was done in split plots to half-tree height (first 4 m) on the previously released dominant and codominant trees. The first results (after 10 years) were published by Robitaille *et al.* (1990), and followed by measurements up to 23 years (Figure 10).

New 2012 study: commercial thinning in a 41-year-old stand

Before commercial thinning in the **fall of 2012**, the stand averaged 22.4 m²/ha (100 ft²/ac) and was approximately at 75% of the A-line density (Figure 11). The stand was composed of 58% YB, 22% aspen and 10% maples, with 65% acceptable growing stock (AGS), considering all species, but only 45% for desired species (YB, SM and paper birch). Among these, the best crop trees (with a potential butt log of grade B or better) represented only 120 trees/ha or 14% of the BA.

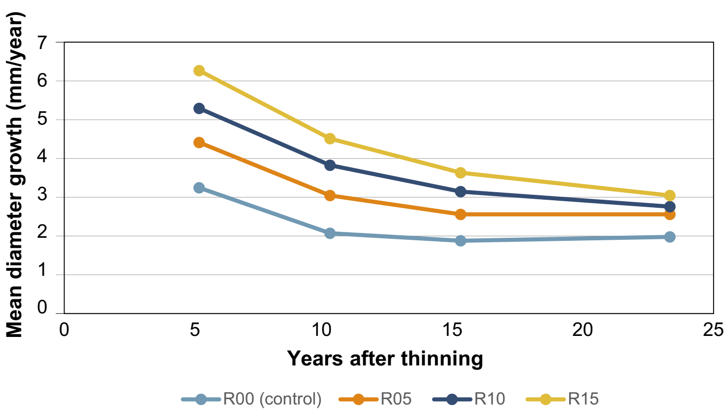

Figure 10. Mean diameter growth of all released trees 5, 10, 15 and 23 years after thinning, according to the radius of bole thinning (R00: control, R05: 0.5-m radius, R10: 1.0-m radius, R15: 1.5-m radius).

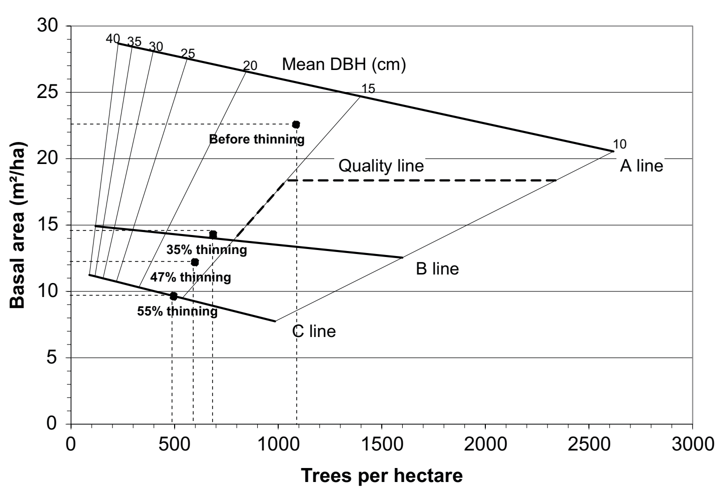

Figure 11. Stocking guide adapted from Leak *et al.* (1987).

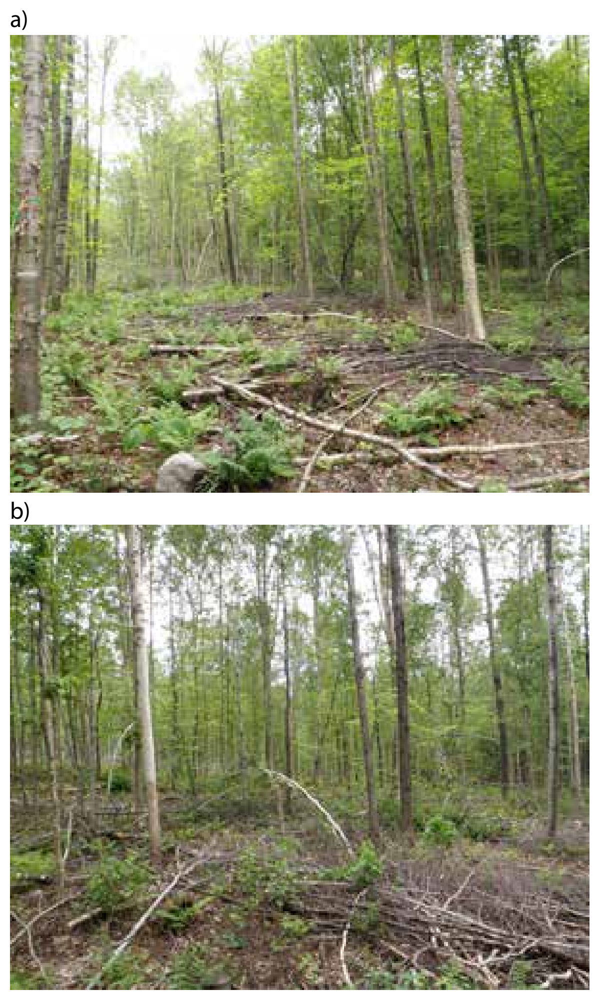

Figure 12. Overview of the 35% (a) and the 47% (b) thinning treatments. Photos : François Guillemette.

The main objectives of the thinning were to enhance the growth of the best crop trees and to prepare conversion back to an uneven-aged stand. This meant: 1) to increase the proportion of SM and to prepare the seed trees; 2) to reduce aspen abundance and the risk of root sprouts at the time of regeneration; 3) to reduce pin cherry abundance by enhancing the germination of its seed bank, with the hope that they will die in the understory.

Four commercial thinning treatments were applied in fall 2012:

- a control (no thinning);
- a 35% thinning to a BA of 14.6 m^2/ha (B line), with 60 trees/ha marked for release (Figure 12a);
- a 47% thinning to a BA of 12.3 m^2/ha (between B and C lines), with 140 trees/ha marked for release (Figure 12b);
- a 55% thinning to a BA of 9.9 m^2/ha (C line), with 200 trees/ha marked for release.

The harvester operator was instructed to cut the 2 largest neighbours within a 6-m radius of the marked trees. Approximately 24% of the initial BA was harvested in trails (4.5-m trails every 20 m). These thinnings were mixed: a mechanical thinning due to the trails and a thinning from above between the trails.

Released crop trees

The released crop trees had a mean height of 18.6 m. Their crown base was at a height of 11.0 m, for a crown proportion of 41%.

The practice of commercial thinning in such young stands implies the creation of permanent logging trails for the first entry. The important proportion of the harvest attributed to these trails limits the number of crop trees that can be heavily released.

Table 1. Descriptive statistics of crop trees in the various treatments.

Treatment	Density (n/ha)	Density of uninjured trees (n/ha)	Crown radius (m)	Released radius (m)
14.6 m^2/ha	64	54	2.1	2.4
12.3 m^2/ha	140	114	2.0	2.9
9.9 m^2/ha	189	138	2.0	3.9
Control	--	--	2.2	0.2

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Day 1, Stop 3: Selection cutting

Rehabilitation of uneven-aged northern hardwood stands using the selection system

Steve Bédard, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
Collaborators: François Guillemette, Martin-Michel Gauthier and Filip Havreljuk

Context

Until the early 1980s, hardwood forests were logged using the diameter-limit method, in which stem removal targeted only the highest quality trees for lumber. This practice greatly reduced the allowable cut for lumber for quality hardwoods. In order to maintain stand potential and to ensure sustained yield of hardwoods in the future, silvicultural practices had to change. Selection cutting was therefore proposed for stands dominated by sugar maple and that still had enough acceptable growing stock. Since 1983, studies on selection cutting were undertaken by Zoran Majcen in several types of hardwood forests.

Objectives

This project studies stand dynamics following single-tree and group selection cuttings. More specifically, its initial objectives were to evaluate the effects of the selection system on stand structure, growth and yield, and regeneration. Recently, additional work was undertaken to study the effects of selection cutting on tree quality and wood value, as well as on the conservation of old growth forest attributes (large-diameter trees, snags, coarse woody debris).

Study details

Our provincial research network covers most of southern Québec, with more than 20 research locations and 60 paired plots (Figure 5a, blue symbols). Each pair of plots comprises a harvested plot (100 m × 200 m, or 2 ha) and an untreated control plot (100 m × 100 m, or 1 ha). Tree marking prior to cutting was carried out using a theoretical distribution based on a *q* factor, a target basal area and a specific maximum diameter for each stand. Tree marking targeted primarily low-vigor stems that were likely to die or to lose quality during the next cutting cycle (20 years). Trees of each plot were measured with a caliper, both before the cut and after 10 years. A subplot (100 m × 50 m, or 0.5 ha) was also established in all plots after the cut and measured at 5-year intervals. Merchantable trees (dbh ≥ 10 cm) and saplings (2 cm ≤ dbh ≤ 8 cm) were measured from the beginning of the study. Tree vigor was evaluated since the beginning of the 1990s. Tree quality was evaluated for trees of dbh > 23 cm since 2005 in the 0.5-ha subplots. More recently, some of the oldest plots in stands established between 1983 and 1990 were cut for a second time. A sample of the harvested trees were bucked into logs to evaluate log product assortment.

At the Duchesnay location, 10 paired plots were established from 1988 to 1999. This paper presents results for 7 of these, established from 1990 to 1996 in several sugar maple–yellow birch–American beech stands. Table 2 presents the basal area, volume, and main species composition of these stands, before and immediately after cutting (Figure 13).

Figure 13. Overview of the stand in the DU1993 experimental plot after the second selection cutting, showing the American beech recruitment into the pole-size class. Photo : François Guillemette.

Table 2. Average basal area, volume and species proportion before and after selection cutting at the Duchesnay sites, based on measurements of 0.5-ha subplots within 7 paired plots established from 1990 to 1996.

Treatment	Basal area (m^2/ha)		Volume (m^3/ha)		Composition (% volume): Sugar maple		Yellow birch		American beech		Other species	
	Mean	± s.e.	Mean	± s.e.	Mean	± s.e.	Mean	± s.e.	Mean	± s.e.	Mean	± s.e.
Control	23.1	± 0.6	193.3	± 6.0	40.2	± 7.1	34.2	± 5.9	13.8	± 4.1	11.7	± 3.3
Selection cutting - Precut	24.6	± 0.5	202.8	± 7.8	44.7	± 6.6	26.4	± 6.5	19.4	± 7.1	9.6	± 2.4
Selection cutting - Postcut	17.9	± 0.4	146.6	± 4.4	46.9	± 6.9	30.9	± 6.9	14.3	± 6.2	8.3	± 2.4

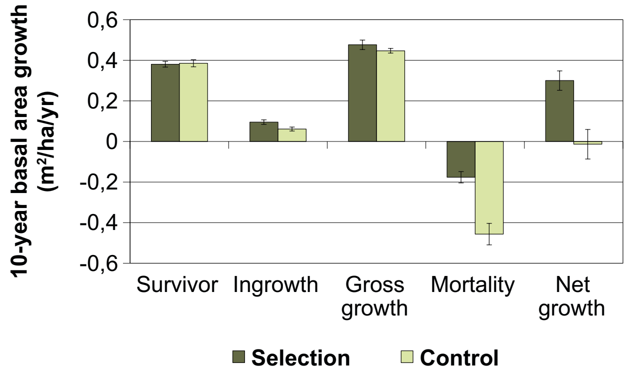

Figure 14. Mean basal area growth after 10 years at Duchesnay, based on measurements of 0.5-ha subplots within 7 paired plots (selection cutting *vs* control) established from 1990 to 1996. Error bars represent standard error.

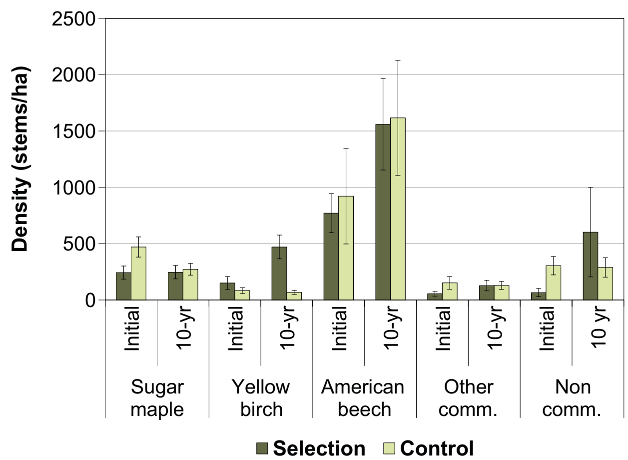

Figure 15. Mean number of saplings at Duchesnay, based on measurements of 0.5-ha subplots within 7 paired plots (selection cutting vs control) established from 1990 to 1996. Error bars represent standard error.

Figure 16. Small group of saplings in the DU1992 experimental plot. Photo : François Guillemette.

Preliminary results

Net growth and mortality (Figure 14):

- After 10 years (mid-cutting cycle), trees had better net growth and less mortality in all cutting treatments compared to the control.
- However, mortality in treated stands was high, and production was 20% less than expected during the first cutting cycle.
- We expect high mortality of American beech in the coming years due to the beech bark disease.

Regeneration (saplings) (Figures 15 and 16):

- American beech saplings are abundant and strongly compete with sugar maple and yellow birch. However, the study site at Duchesnay is not optimal for sugar maple regeneration, due to a thick humus layer, acidic soils with poor calcium content.
- Small openings (200–400 m^2) with passive soil scarification during fall logging operations favored yellow birch regeneration. However, there was less cervid browsing in the 1990s than today. Consequently, we do not expect as much birch regeneration in the future.

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Northern hardwood silviculture wrap-up and discussion

Evolution of northern hardwood silviculture across North America: trends in application and current issues

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Northern hardwood forests represent the dominant forest type across large portions of northeastern North America and their management has correspondingly been a primary research focus in this region for more than 80 years. Despite the commonalities in dominant overstory tree species across the extensive range of this forest type, there is tremendous variation in the site conditions and land-use histories associated with northern hardwoods that result in unique suites of management challenges within any given portion of this range. Accordingly, the effectiveness of different silvicultural systems at sustaining this resource has also varied considerably, resulting in great variety in the ways in which northern hardwood silviculture is currently practiced.

The earliest research on northern hardwood silviculture began in the 1920s and 1930s and was focused on generating a sustained yield from the "old-growth" hardwood stands that were often the residual condition following a wave of selective logging for white pine in the Lake States and for red spruce in the northeast in the late 19th and early 20th centuries. Early studies at both the Dukes Experimental Forest in the Upper Peninsula of Michigan and the Bartlett Experimental Forest in the White Mountains of New Hampshire were central to the development of silvicultural guidelines for these forests. They emphasized uneven-aged approaches, particularly single-tree selection, to generate balanced, uneven-aged structures for the sustainable management of these stands. Although other early studies at these locations demonstrated the value of group and patch selection approaches for sustaining less tolerant species, such as yellow birch, the application of single-tree selection based on empirically-derived marking guides, such as the Arbogast Guide, quickly became the suggested approach for these forests. Single-tree selection based on this early work remains a key element of northern hardwood silviculture across the region; however, it is now viewed less as a panacea for all stands and objectives and, instead, as one potential approach amongst several potential alternatives.

Several factors have led to a broadening of silvicultural approaches beyond solely single-tree selection in northern hardwoods. The first has been the realization of the long-term compositional outcomes of this approach, as numerous works have demonstrated homogenization of species composition towards sugar maple and American beech following long-term application of single-tree selection on rich and moderate sites, respectively (Figure 17). A second factor has been the challenges associated with applying this method to second-growth northern hardwoods, which often lack the age structures and quality required to sustain this approach. Finally, this method requires the greatest amounts of time and skill for marking a given stand resulting in either misapplication or practitioners opting for a more operationally efficient uneven-aged method, like group or patch selection.

a)

b)

Figure 17. Dominance of sugar maple (a) and American beech (b) across canopy layers following long-term application of single-tree selection on a rich site in the Upper Peninsula of Michigan (a) and a moderate site in New Hampshire (b). Note the lack of sapling size class in (a), due to high levels of herbivory. Photos: Anthony D'Amato.

Beyond the operational efficiencies afforded by group and patch selection, the desire to increase and maintain tree species diversity and transition second-growth forests to uneven-aged structures has led to the increasing application of these methods across the geographic range of northern hardwoods over the past two decades. In most cases, these systems are being applied to increase yellow birch abundance, and typically rely on harvest gaps ranging from 1/4–1/3 acre (0.1–0.15 ha) (Figure 18). The importance of removing existing American beech and sugar maple advance regeneration from these group openings to enhance regeneration diversity is being increasingly recognized, particularly in areas where beech bark disease or past partial cuttings have resulted in dense understories dominated by shade-tolerant species. Similarly, long-term outcomes of extended and continuous cover irregular shelterwoods removing American beech at the establishment cutting indicate these systems may also be effective for rehabilitating compositional and structural conditions on sites with a history of diameter-limit cutting. Integrated across these approaches has been an increased recognition of the importance of incorporating the retention of live and dead tree legacies into regeneration entries to meet ecological objectives (Figure 19).

Despite the great gains in our understanding of the range of possible approaches to northern hardwood silviculture over the past 50 years, current and projected future forest conditions present an increasing array of challenges to sustaining desired outcomes from these forest over time. In the Lake States, European earthworms have already fundamentally altered soil structure and vegetation conditions across many northern hardwood systems, generating significant bottlenecks for future sugar maple recruitment (Figure 20). Similarly, in many areas, elevated deer densities have shifted understory conditions away from sugar maple towards less palatable species, such as American beech, further exacerbating the influence of beech bark disease on regeneration dynamics in many northern hardwood forests. As with controlling American beech, the use of site preparation and release treatments have become increasingly important for reducing the influence of recalcitrant layers of invasive and native plant species on regeneration outcomes (Figure 21); an investment never anticipated by

a)

b)

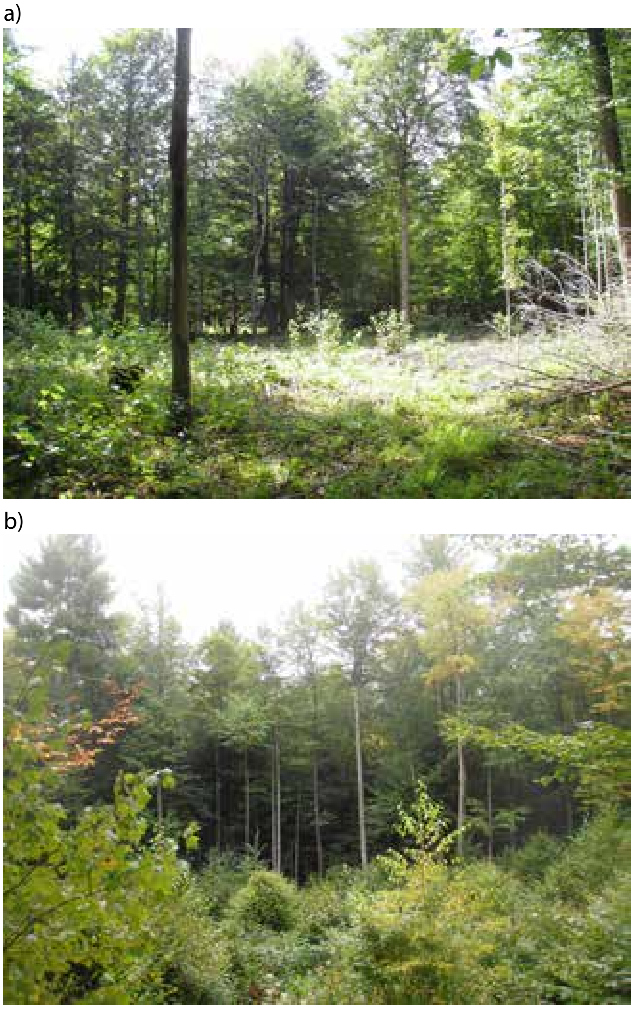

Figure 18. Group selection harvest (1/4-acre opening) in the Adirondacks, New York (a) and 1/3-acre patch selection harvest in western Massachusetts (b), in which all pre-existing advance American beech regeneration was felled at the time of gap creation (note large birch saplings 6 years post-harvest). Photos: Anthony D'Amato.

a)

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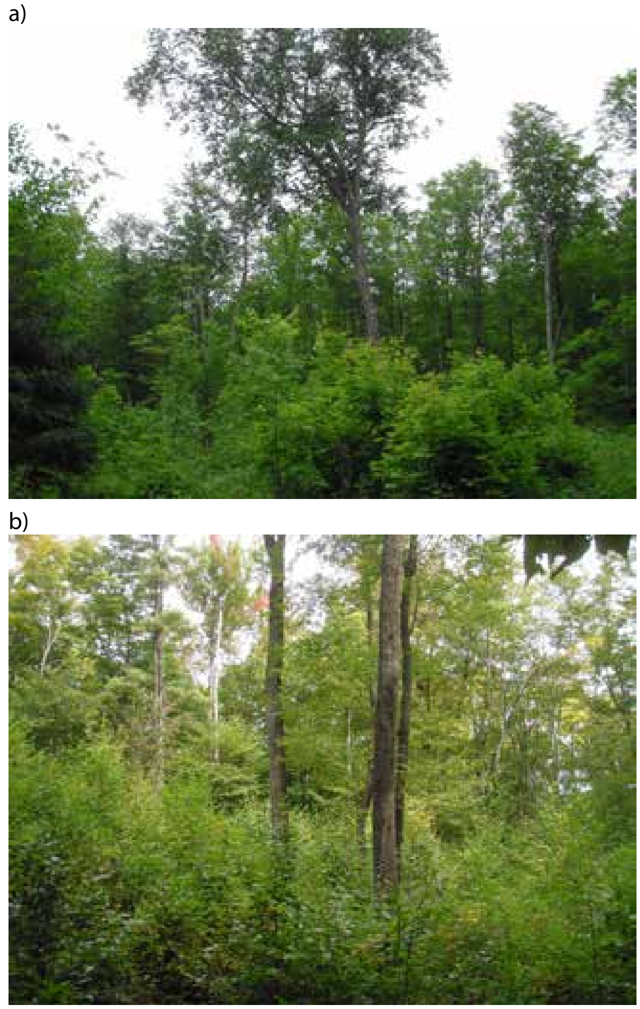

Figure 19. Retention of yellow birch seed tree within a group selection opening in the Upper Peninsula of Michigan (a) and of white ash legacy trees for maintenance of mature forest structure within a patch selection harvest in western Massachusetts (b). Photos: Anthony D'Amato.

early forest scientists working in these forests. Over time, these changes will increasingly interact with shifting climate regimes and introduced insects and diseases, requiring a recalibration of the silvicultural toolbox that has proven so adept at adapting to changing forest conditions in the northern hardwood resource over the past 80 years. As with past evolution of practice, the importance of developing and refining selection- and irregular shelterwood-based approaches that generate and maintain diverse compositional and structural conditions will be critical for sustaining multiple recovery and regeneration pathways for this forest type in an increasingly uncertain future.

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Figure 20. Dense sedge layer on a site infested with European earthworms in northern Wisconsin. Photo: Anthony D'Amato.

Figure 21. Scarification of group selection opening in northern Wisconsin to reduce cover of Pennsylvania sedge and increase mineral soil seed beds. Photos: Karin Fassnacht.

Day 2 — Portneuf County: Mixedwood silviculture

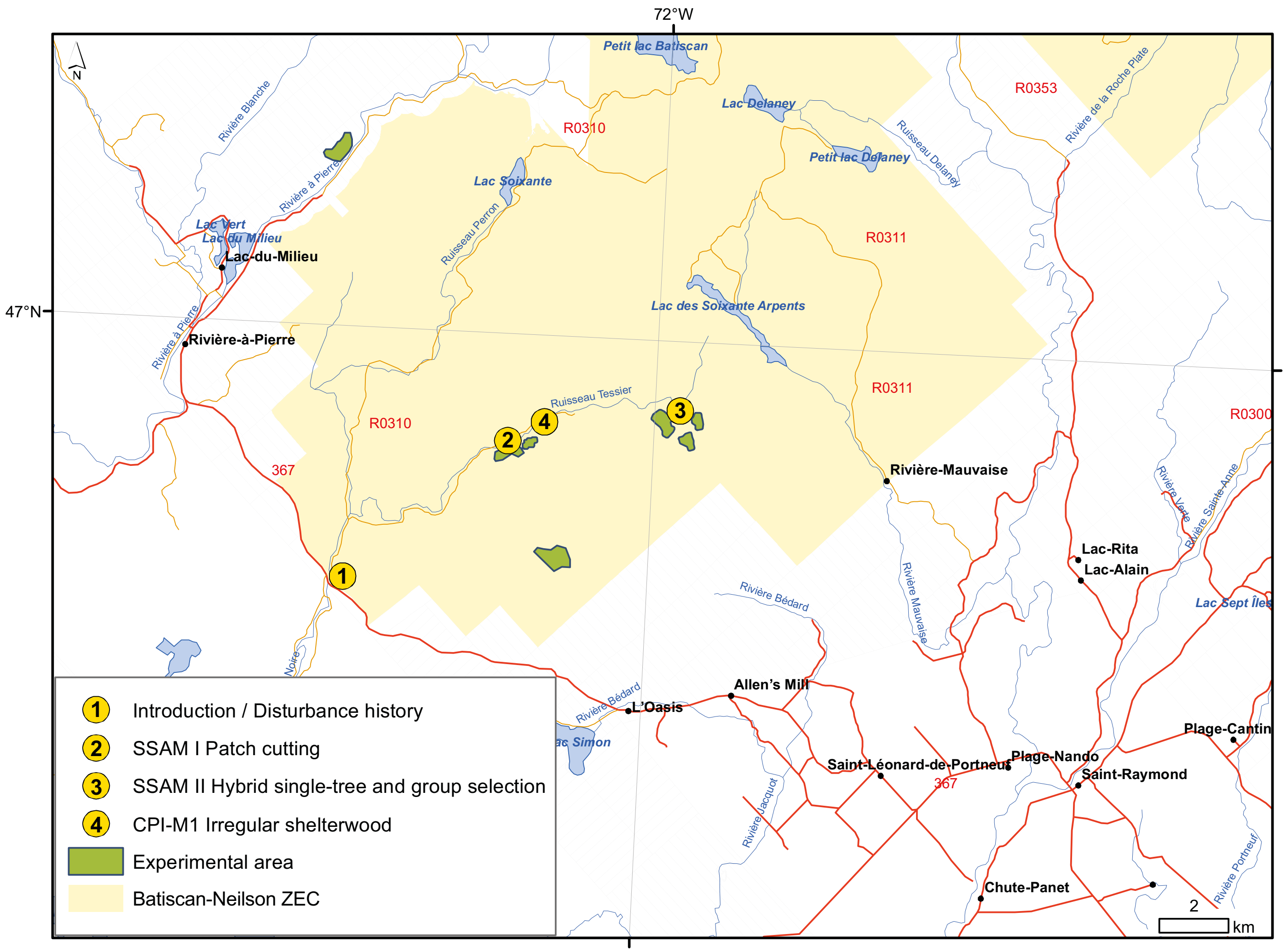
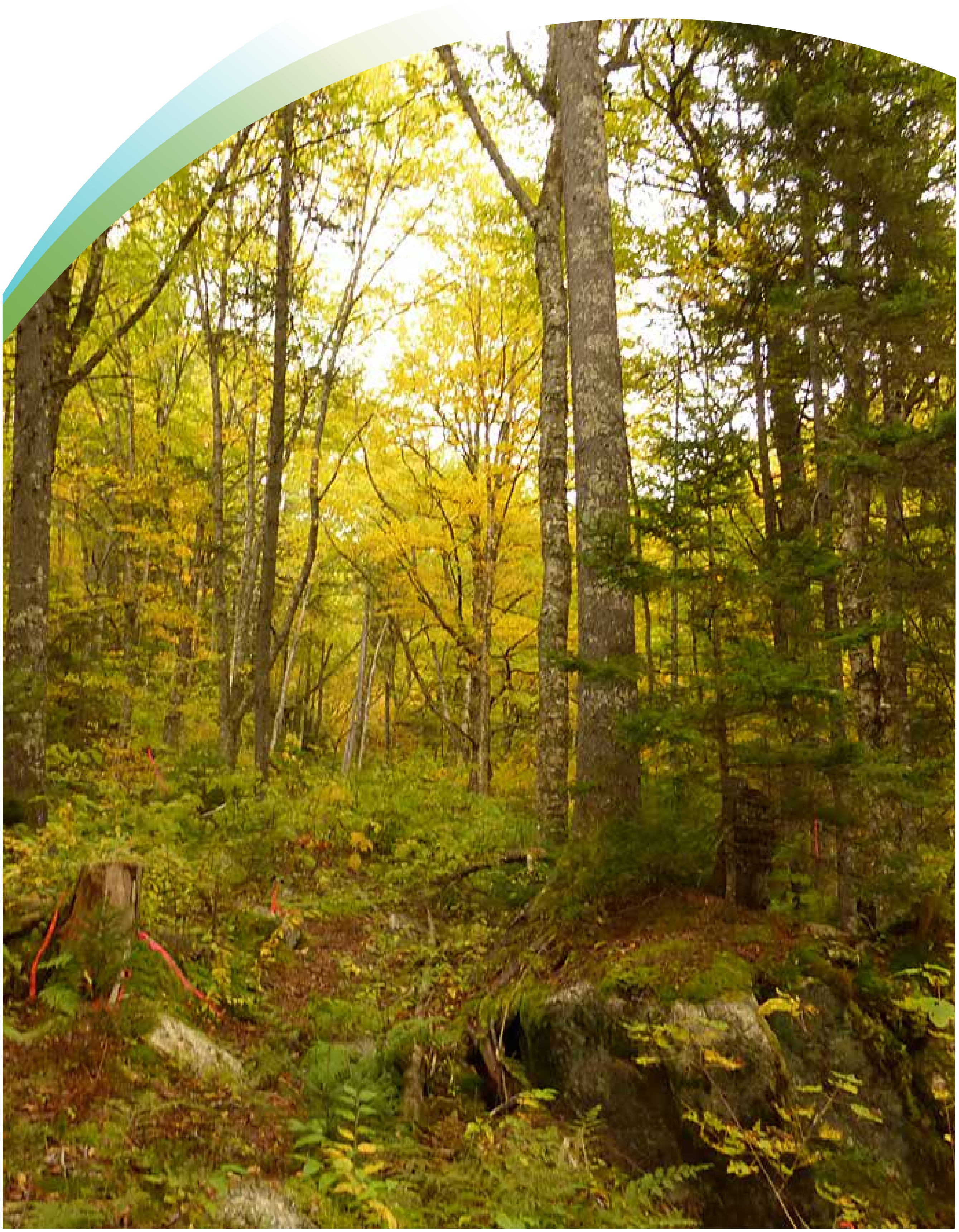


Figure 22. Map of the sites visited in Portneuf County.


Patricia Raymond

Introduction to mixedwood management and silviculture in Québec

Patricia Raymond, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs

Represented by the balsam fir–yellow birch bioclimatic domain (Figure 4), Québec's temperate mixedwood forest is the transitional zone between the deciduous and the boreal forests. Located near inhabited areas, this productive forest has been used for two centuries for wood production, but also for recreational activities. This forest has high economic, social and environmental value. For a long time, unregulated harvests and even-aged systems have contributed to decrease the representation of conifers and old-growth forests in the landscape.

During the 1980s, Quebecers — who own 90% of forest land — raised questions about the health and management of their forests. They were concerned by the use of chemical insecticides to control spruce budworm outbreaks and by the use of herbicides to manage competing vegetation in cutovers. These issues prompted a major public consultation that resulted in 54 recommendations grouped in a legally binding *Forest Protection Strategy* (MRN 1994). This achievements represents a turning point in our province's forest management and silviculture. Chemical insecticides and herbicides have been prohibited on public land since 2001, and alternative methods had to be developed. Diameter-limit cuttings are forbidden because they are considered as a harvesting method rather than a silvicultural treatment. Finally, stand conversion from hardwood or mixedwood forests to conifer plantations is not allowed anymore.

Mixedwood management was finally put into practice in the 1990s, with the publication of a *Forest Management Guide* (MRN 1992) that assigned treatments to mixedwood stands. The first treatments, however, mostly mimicked the typical softwood management approach used in conifer-dominated mixedwood stands, or that for hardwood management in hardwood-dominated mixedwood stands. Since these models were difficult to apply to mixedwood stands, the desired production goals were not necessarily achieved. Managers and silviculturists came to agree about the need to develop a silviculture genuinely adapted to mixedwood stands.

The overarching principles of Québec's *Forest Protection Strategy* (MRN 1994) are to manage for diversity in order to increase resistance to pests and productivity, to respect natural dynamics in order to limit problems with interspecific competition, to rely on natural regeneration whenever possible, and to develop a preventive silviculture approach. Applying all these new ideas to mixedwood silviculture required a considerable research effort in Québec. A new research program on mixedwood silviculture has been led by Marcel Prévost at the *Direction de la recherche forestière*. Over the next two days, we will have the pleasure of touring 4 of its experiments that were established over the last 16 years.

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Day 2, Stop 1: Disturbance history

Natural and anthropogenic disturbance regimes in the temperate mixedwood forest

Yan Boucher, Research biologist, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs

The temperate mixedwood forest is probably the area in eastern Canada that is the most affected by natural and anthropic disturbances of various sizes and levels of severity. Typically, natural forest dynamics are mainly governed by disturbances such as wildfires, spruce budworm outbreaks and canopy gaps. In addition, over the last two centuries, human activities such as clearings for settlement, escaped-settlement fires and logging have considerably modified the natural disturbances regimes. From several ecological studies conducted across Québec's temperate mixedwood forest, I will portray the main characteristics of natural disturbances and the chronology of human activities that have affected forest dynamics over the last two centuries and shaped the present-day forest landscape.

This text can be cited as follows:

Boucher, Y., 2016. Natural and anthropogenic disturbance regimes in the temperate mixedwood forest. In: Ministère des Forêts, de la Faune et des Parcs (ed.), 2016. *Multi-aged silviculture of northern hardwood and mixedwood forests. Proceedings — Field tour in Québec.* Hosted by the ministère des Forêts, de la Faune et des Parcs and the New England Society of American Foresters Silviculture Working Group. August 24–26, 2016. Québec, QC, Canada. p. 24.

Photo: Yan Boucher

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Photo: Archives nationales du Québec, P666

Photo: Patricia Raymond

Day 2, Stop 2: Patch cutting

The SSAM Project: Assessing a gap-based approach to maintain the composition and structure of yellow birch–conifer stands

Patricia Raymond, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
Collaborators: Marcel Prévost, Hugues Power and Jean-Martin Lussier

Mixedwood management has been practiced in Québec for nearly 25 years, with the objective of maintaining biodiversity and improving resistance to pests. Managing mixed productions of hardwoods and softwoods in the yellow birch–conifer forest type is challenging because of the diversity of tree species, their contrasting ecological characteristics, and the presence of dense recalcitrant layers made of shrub species like mountain maple, striped maple, mooseberry and pin cherry.

Established in 1999, the SSAM project (Silvicultural Systems Adapted to the Mixedwood forest) was among the first to aim at regenerating a mixture of hardwoods (e.g., yellow birch) and softwoods (e.g., red spruce and balsam fir) in Québec. In line with natural disturbance-based management, we hypothesized that treatments designed to incorporate gaps could regenerate these species and contribute to minimizing impacts on plant diversity. This experiment comprises 20 experimental units (1 ha each) and tests 5 treatments: an uncut control, a patch clearcut and three 50% patch-selection cutting patterns that combine harvest by circular gaps (20 m, 30 m, 40 m, hereafter referred to as 1, 1.5 and 2H, respectively; H = height of the dominant trees), and a 33% single-tree cutting. Spot scarification with an excavator was applied as a sub-treatment on half of the openings, at a density >1 000 spots/ha (Figure 23).

An initial seedling survey (6 years) indicated that the 3 patch cutting treatments combined with active spot scarification resulted in the highest yellow birch seedling densities. However, none of the cutting treatments were successful in promoting conifers because of the heavy interspecific competition (Prévost *et al.* 2010). Further study of the regeneration niches within the patch cutting treatments revealed that the border of openings played an important role in balsam fir regeneration, hinting that smaller gaps could promote shade-tolerant conifer regeneration.

The 10-year growth and yield assessment of the partially cut between-patch matrix showed that recruitment and growth gains were offset by mortality losses (mostly for balsam fir). As a result, stand net merchantable basal area did not change significantly (Raymond *et al.* 2016). Mortality rate modeled at the tree-level was higher for trees with larger diameters, defects, and high crown ratios. Trees with small diameters and those located along the border of harvest gaps had the largest increments in basal area. We also observed a high percentage of epicormic branching on border trees.

Figure 23. Spot scarification was performed by an excavator (a) to produce 1 m x 2 m spots (b) with the goal to establish yellow birch regeneration (c). Photos: Daniel Kneeshaw (a, b) and Patricia Raymond (c).

Overall, our first decennial results bring us to question the use of patch cutting in mixed uneven-aged stands that comprise an important component of short-lived balsam fir. Silvicultural systems in which various-sized gaps are not placed systematically may prove better for managing wood production and complexity in yellow birch–conifer stands.

Two years ago, we resampled our regeneration monitoring network to assess the composition and density of the sapling layer. These preliminary 15-year results show a persistence of mountain maple as dominant species in all treatments except the patch clearcut (Figure 24). Treatments did not significantly affect mountain maple and red maple densities, but had positive effects on yellow birch ($p < 0.001$) and balsam fir ($p = 0.015$). Saplings of both species were more abundant in the patch clearcut than in the uncut control, 1H and 1.5H patch cutting treatments.

The effects of scarification still persisted after 15 years, since yellow birch densities were 3 times more abundant in scarified than in non-scarified areas ($p < 0.001$). Most pin cherry stems were damaged by fungi and gave way to other species, although this species had initially been very abundant in patch clearcuts. Red spruce was still nearly absent from the sapling layer, even if it initially represented 15% of stand basal area. The long-term maintenance of red spruce in the stand appears very uncertain. The poor results obtained so far in yellow birch–conifer stands emphasize the need for experimenting other silvicultural scenarios, such as enrichment planting in harvest gaps when advance regeneration is scarce.

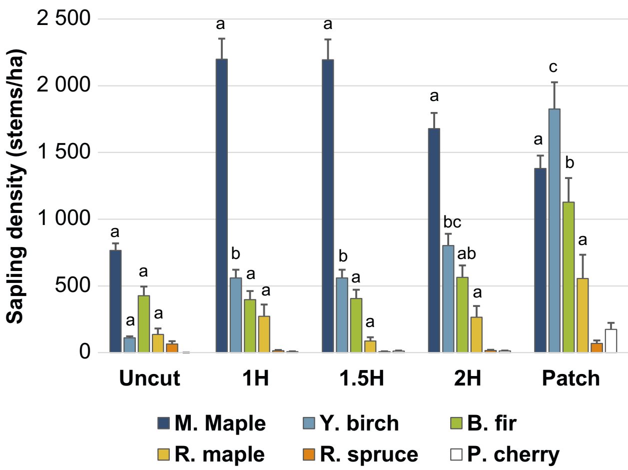

Figure 24. Mean sapling density (2-8 cm dbh) of vigorous stems after 15 years, for various patch cutting treatments. Differing letters indicate differences among treatments for a given species (M. maple: mountain maple; Y. Birch: yellow birch; B. fir: balsam fir; R. maple: red maple; R. spruce: red spruce; P. cherry: pin cherry).

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Day 2, Stop 3: Hybrid single-tree and group selection cutting

Enrichment planting in small groups to sustain the red spruce component in yellow birch–conifer stands: the ecophysiological response

Daniel Dumais, Research forester, Direction de la recherche forestière, ministère des Forêts, de la Faune et des Parcs
Collaborators: Patricia Raymond and Marcel Prévost

In Québec, red spruce decline in managed stands of temperate mixedwood forests is a major biodiversity challenge. This desired conifer species is particularly difficult to regenerate after cutting. Consequently, it is important for forest managers to first build on the species' valuable advance regeneration, pending new solutions to help establish seedlings.

Our previous ecophysiological studies (Dumais and Prévost 2008, 2014) demonstrated that uniform partial cuts that left a residual merchantable basal area (BA) of 13 to 19 m^2/ha or medium 100- to 300-m^2 gaps were favorable to the protection, acclimation and regrowth of red spruce advance regeneration in rich yellow birch–conifer stands. However, in the first experimental site of the SSAM project (Silvicultural Systems Adapted to Mixedwood stands), red spruce proved very hard to regenerate when it was not established in the understory prior to cutting. Therefore, in the second SSAM experiment, we test the enrichment planting of red spruce with the aim of reintroducing the species in gaps created by hybrid single-tree and group-selection harvesting of different intensities (Figure 25). Because the abundant shrub competing vegetation is generally problematic for conifer regeneration in temperate mixedwood forests, we used large-sized containerized seedlings (height: 40 cm). Spruce seedlings were planted in the spring of 2009 in the gaps created by 3 group-selection cutting intensities (light, moderate and heavy) which left residual BAs of 19, 17 and 15 m^2/ha. Seedlings were also planted in an uncut control (BA: 26 m^2/ha) for comparison. In July of 2012, competing vegetation was cut with a brush saw on 1 m around half of the planted seedlings. Ecophysiological and growth variables of the planted seedlings was monitored (Figure 26) twice during the growing season for the first 6 years after planting (2010–2015).

Preliminary results from these first 6 years of observations indicate that none of the cutting treatments reduced daytime shoot water potential (values around −1.0 MPa) of planted seedlings. This indicates that none of the tested treatments caused an additional water stress to the planted seedlings. Six-year light-saturated photosynthesis (A_{max}) increased proportionally to cutting intensity (from ~ 7 µmol/m^2/s of CO_2 in the control to ~ 10 µmol/m^2/s in the heavy cut), indicating a physiological acclimation of seedlings. An effect of the competing vegetation removal on A_{max} (gain of 1.5 µmol/m^2/s) was only observed in the heavy cut. Specific leaf area (SLA) of the planted red spruce seedlings decreased with cutting intensity (71 cm^2/g for the control, and 59, 58 and 54 cm^2/g for the light, moderate and heavy cuts, respectively), indicating morphological acclimation of the foliage. This result contrasts with our previous observations made on advance red spruce regeneration, for which

Figure 25. Seven-year-old red spruce seedling, 5 years after planting. Photo: Daniel Dumais.

only complete canopy removal or a large canopy opening (e.g., 700 m^2) resulted in a rapid SLA adjustment in the few surviving red spruces (Dumais and Prévost 2008, 2014). Apparently, planted seedlings that were cultivated in open nursery conditions could more rapidly take advantage of moderate to high light conditions than pre-established seedlings.

Growth variables of planted red spruce seedlings were positively influenced by partial cutting, in interaction with the removal of competing vegetation. Globally, mean annual height increment over 6 years varied from 1.6 cm/year in the control to 16.8 cm/year in the heavy cutting treatment. Though A_{max} did not increase in light and moderate cuts following the removal of competing vegetation, the release treatment increased seedling height growth in all cutting treatments. Therefore, in the presence of competing vegetation, planted seedlings seem to allocate less carbon to height growth. This could be because they allocate more resources to root growth in order to compete for water and nutrients. Measurements in 2015 show that total (6-year) height growth increased with cutting intensity (58 cm in the control, 89, 98 and 103 cm in the light, moderate and heavy cuts, respectively). Collar diameter in 2015 also increased with cutting intensity (from 7 mm in the control to 20 mm in the heavy cut). Finally, we also observed gains in height (up to +20 cm) and diameter (up to +4 mm) related to the removal of competing vegetation.

According to the preliminary results of this ecophysiological study, red spruce enrichment planting in gaps created by the harvest of small groups of trees, combined with local control of competing vegetation, appears as a promising approach for the reintroduction of the species in the understory when it is nearly absent from the advance regeneration. Partial removal of the forest cover seems necessary to provide enough resources to permit survival and growth.

Figure 26. Gas exchange measurements (including photosynthesis) on a planted red spruce seedling. Photo : Daniel Dumais.

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Day 2, Stop 4: Irregular shelterwood system

Irregular shelterwood as an alternative to clearcutting in balsam fir–yellow birch stands

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Collaborators: Steve Bédard, Stéphane Tremblay, Catherine Larouche and Daniel Dumais

Because of their simplicity of application and their short-term economic benefits, even-aged systems have been used in North America to manage conifer-dominated stands with the goal of normalizing the forest and reaching sustainable wood production. At the landscape scale, however, the widespread use of clearcutting and its variants has had the effect of simplifying the age-class structure, increasing the representation of young stands and increasing the proportion of hardwoods to the detriment of conifers. At the stand scale, applying even-aged systems to irregular stands can sacrifice small, vigorous and merchantable trees, simplify the within-stand structure and alter biodiversity.

In this experiment, we compare the effects of irregular shelterwood scenarios to those of careful logging and to uncut control stands on the regeneration of balsam fir–yellow birch irregular stands. This study is part of a larger experiment that aims to assess the possibilities of using irregular shelterwood to maintain the structure of irregular stands while producing high-quality timber and maintaining old-growth structural attributes. Maintaining stand structure with the irregular shelterwood system is based on the hypothesis that each regeneration cut creates growing space for the establishment of a new regeneration cohort, while enhancing growing conditions to release the older cohorts (Raymond *et al.* 2009).

The experiment was established in 2009 in irregular balsam fir–yellow birch stands with an average BA of 31 m^2/ha (45% balsam fir, 24% red spruce, 16% red maple and 12% yellow birch). Tested scenarios include an uncut control, 25% continuous cover irregular shelterwood (no final cut), 40% extended irregular shelterwood (final cut at year 30), 50% uniform regular shelterwood (final cut at year 10), and careful logging (clearcut with protection of trees <9.1 cm dbh, hereafter called "clearcut")(Raymond *et al*., in prep.).

After the cut, the 25% continuous cover maintained a diameter structure closest to that of the uncut stand (Figure 27). Careful logging decreased the number of standing dead trees compared to other treatments. The shelterwood treatments doubled the % transmitted light compared to the uncut control (32% *vs* 16%). Transmitted light was inversely correlated to basal area (R^2 = 0.88); immediately after the cut, it averaged 27% to 38% in the shelterwood treatments. After 5 years, the 25% continuous cover irregular shelterwood treatment was the most favorable to early establishment of red spruce and balsam fir seedlings (<30 cm) (Figure 28). All cutting treatments significantly increased the density of yellow birch seedlings (>30 cm) during the 5-year period.

Figure 27. After 5 years, the 25% continuous cover irregular shelterwood treatment could maintain a stand structure and a competition cover closer to that of the uncut control, while providing favorable conditions to the establishment of red spruce, balsam fir and yellow birch.
Photo : Patricia Raymond.

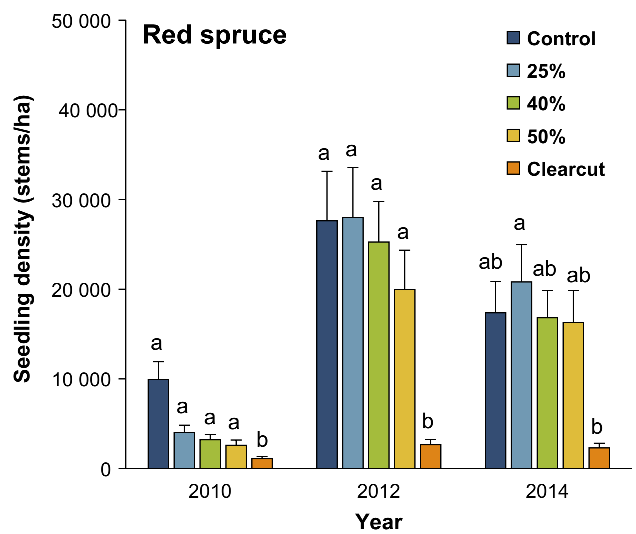

Figure 28. Significant interaction between cutting treatments and years on red spruce seedling density (<30 cm). Error bars represent standard error. For each year, letters above the bars show significant differences between means (α = 0.05).

Cutting treatments also influenced the response of competing vegetation. Red maple, the most aggressive competitor on these sites, increased markedly in treatments where 40% and more of the basal area was harvested. All shelterwood treatments had lower pin cherry coverage than the clearcut treatment. Overall, competing species expanded the most in the clearcut compared to the control. After 5 years, the lightest shelterwood cut (25%) kept the competing species cover at a level closer to the control, and significantly lower than in the clearcut.

Our 5-year results indicate that irregular shelterwood scenarios could promote regeneration in conifer-dominated mixedwood stands and are a potential alternative to clearcutting. Longer-term observations will be necessary to identify the best scenarios.

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Day 3 — Lower Saint-Maurice: Mixedwood silviculture *(continued)*

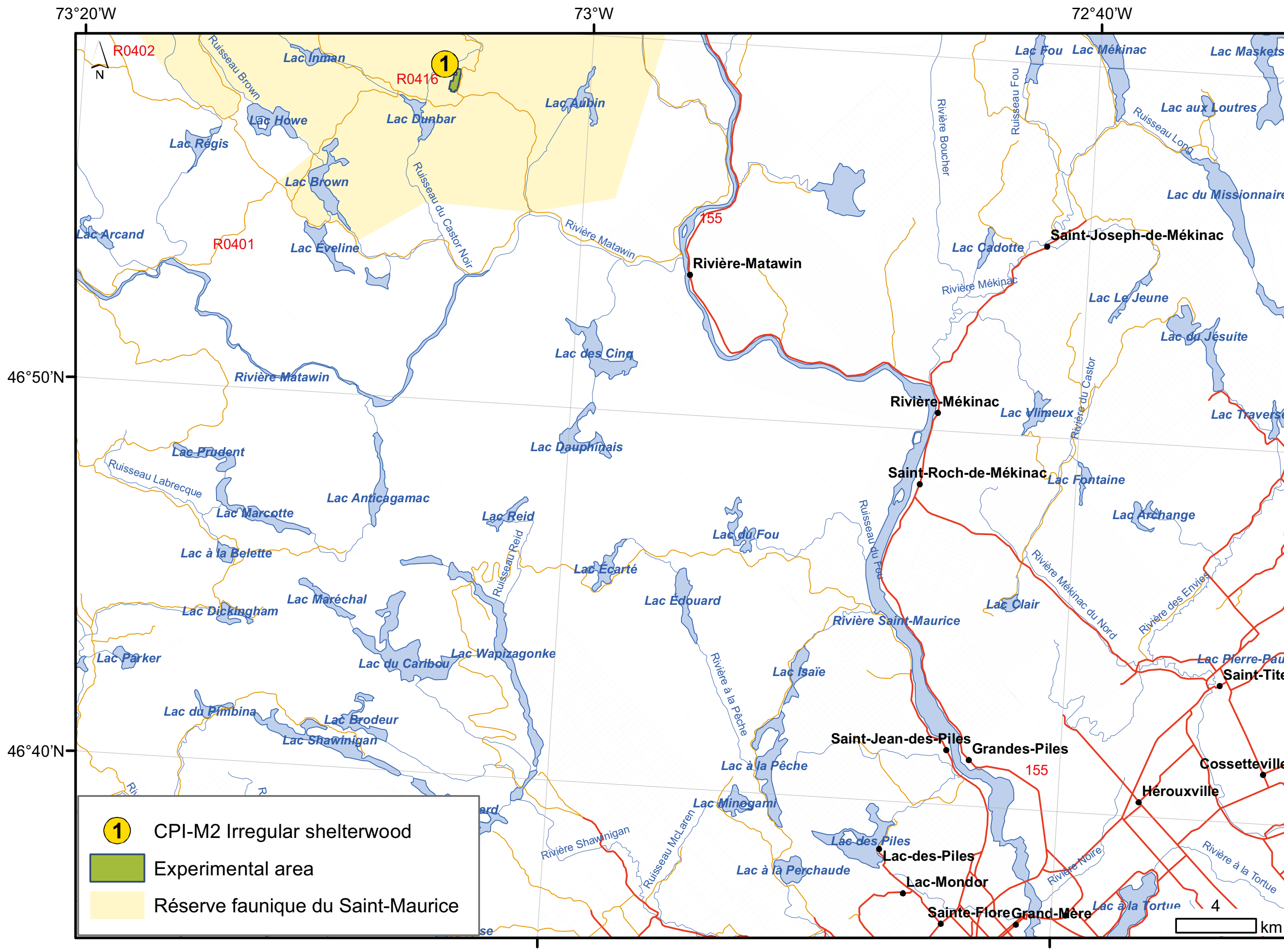

Figure 29. Location of the visited site within the *Réserve faunique du Saint-Maurice*.

Day 3, Stop 1: Irregular shelterwood system

Assessing the intermediate disturbance hypothesis with the irregular shelterwood system in yellow birch–conifer stands

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Yellow birch–conifer stands are the most productive of the temperate mixedwood forest zone. They grow on rich mesic sites that support a diverse forest community that is challenging to regenerate, either naturally or artificially. After pesticides were banned on public land in 2001, forest managers opted for a "preventive silviculture" approach that relied largely on partial cutting. Clearcut systems are not used anymore in high-quality stands because they oversimplify the complexity of these stands and favor a rapid invasion of cutovers by competing vegetation.

In the absence of rare stand-replacing disturbances (fire), yellow birch–conifer stands are shaped by a mix of light and moderate disturbances (e.g., natural senescence, insect epidemics, birch decline and windthrow). Gap dynamics are a major driver that allow a variety of species to coexist (Kneeshaw and Prévost 2007). In this experiment, we aim to test irregular shelterwood scenarios to assess the intermediate disturbance hypothesis (Connell 1978) (Figure 30), which states that species richness is maximal under intermediate disturbance levels. It is based on the assumption that both early and late-successional species can survive under these conditions, and that this coexistence increases community diversity.

Figure 30. In this experiment, we attempt to emulate the natural disturbance regime with irregular shelterwood systems, which is considered as a moderate disturbance. Photo: Patricia Raymond.

More specifically, this second irregular shelterwood experiment of our research program in mixedwood stands aims to:

- promote the establishment and growth of yellow birch, eastern white cedar, red spruce and white spruce natural regeneration;
- limit the expansion of non-commercial species in the understory;
- maintain old-growth forest attributes;
- compare the effects of selection and irregular shelterwood cutting systems on growth and yield;
- study the physiological acclimation of both natural and planted red spruce and eastern white cedar seedlings;
- quantify the seasonal habitat use by herbivores and the effect of these animals on stand dynamics (Figure 31);
- assess habitat use by the red-backed salamander under a gradient of partial cuttings (Figure 32).

Figure 31. Twelve 10 m × 10 m exclosures paired with non-exclosure plots, along with pellet sampling and game cameras will allow us to assess the habitat used by large mammals, as well as the effect of these animals on regeneration dynamics. American black bear, white-tailed deer and moose have all been caught by the same camera during the first summer after the cut. Photo : MFFP.

The experiment was set up in 2014 in yellow birch–conifer stands within the *Réserve faunique du Saint-Maurice*, approximately 70 km north of Trois-Rivières. Main species were yellow birch (26%), balsam fir (21%), red maple (17%), eastern white cedar (16%) and red spruce (8%). The experimental design comprises 20 experimental units (EU) of 90 m × 90 m, with 4 blocks of 5 cutting treatments (silvicultural scenarios): uncut

Figure 32. The red-backed salamander population is monitored using 260 wooden boards distributed in the 20 experimental units. Photo: Patricia Raymond.

control (BA: 31 m^2/ha), 30% hybrid group and single-tree selection cutting (residual BA: 22 m^2/ha), 30% and 40% continuous cover irregular shelterwood (residual BA: 22 and 19 m^2/ha, respectively) and 50% extended irregular shelterwood (residual BA: 16 m^2/ha).

We marked trees negatively prior to cutting according to 3 species-related harvesting priorities: 1) **species to control**: aspen, red maple and American beech >20 cm dbh; 2) **acceptable species**: paper birch and balsam fir >20 cm dbh; 3) **species to promote**: yellow birch, sugar maple, spruces, eastern white cedar and eastern white pine (using the Boulet [2005] "MSCR" vigor classification). Additionally, in each EU, we identified 6 living trees >19 cm dbh to leave as legacy trees. The chosen individuals represented long-lived species (cedar, red spruce, yellow birch, eastern white pine), species with sustainability concerns (eastern white pine, cedar or red spruce), and individuals with wildlife value (cavity or fruit trees). Snags (>20 cm dbh) were marked with blue triangles and left standing as much as possible; dangerous ones were felled.

Cutting treatments were applied during the fall of 2014 with a feller buncher and a grapple skidder. In 2015, immediately after the cut, we built 12 wire-woven exclosures (10 m × 10 m, 8' high) to control cervid access in the control, 30% and 50% irregular shelterwood treatments. We paired these exclosures with adjacent non-exclosure plots to monitor the effects of browsing on vegetation dynamics. Several variables were surveyed before and after the cut, such as: understory vegetation; tree growth, vigor and quality; plant diversity; down woody debris; snags; ungulate browsing and abundance (game camera and fecal surveys); salamander population; light environment; and soil temperature. The experiment is currently at its second growing season after the cut. An abundant cohort of yellow birch seedlings is in the process of establishing.

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Mixedwood silviculture wrap-up and discussion

Mixedwood management in the Northeastern United States

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In the Northeast, we recognize mixedwood stands as hardwood–softwood mixtures in which neither component contributes more than 75%–80% of stocking (usually assessed in terms of basal area). Such stands have long been recognized in regional forest type codes used by commercial land managers, i.e., SH for softwood-dominated mixedwoods and HS for hardwood-dominated mixedwoods.

In New England and New York, mixedwood stands occur most frequently in oak–pine, lowland spruce–fir, and mountainous spruce–northern hardwood (*Picea–Acer–Fagus–Betula*) forest types. The mixedwood composition in these forests is largely a function of land use (disturbance) history. For example, in the absence of disturbances that create large canopy gaps and control competing species (i.e., tillage and agricultural abandonment or fire), oak–pine forests, composed of trees of intermediate shade tolerance, tend be followed by more shade-tolerant species such as red maple and eastern hemlock. In contrast, selective logging of spruce from spruce–northern hardwood mixedwoods in mountainous regions of northern New England and New York during the late 1800s and early 1900s largely eliminated this softwood component, with recent inventories now highlighting regional recovery in those stands.

The lowland spruce–fir forest also contains mixedwood stands, with species composition a function of both site and disturbance history. In fact, U.S. Forest Inventory and Analysis data show that the proportion of sprouting hardwoods such as red maple and shade-intolerant hardwoods such as aspen and birch have increased over the long-term in the northeastern spruce–fir forest. Today, monotypic softwood (S) stands are unusual on the managed landscape, except on sites where silvicultural intervention has removed competing hardwoods or where extreme site (very wet or alpine) conditions exclude hardwood species.

The southern part of the Acadian Forest in New England is compositionally different from the spruce–fir or conifer-dominated forests across the border in Canada. The sites we are visiting during this tour, for example, are characterized by spruce, fir and yellow birch. It is a challenge for practitioners in this region to maintain the less-tolerant yellow birch in mixture with shade-tolerant hardwoods.

Yet, spruce–fir–yellow birch is less common to the south, where site conditions (i.e., poor drainage) preclude the growth of quality hardwoods on all but the best sites within the spruce–fir forest. On these "spruce flats" (per M. Westveld, the father of spruce–fir silviculture), a long history of softwood harvesting has resulted in conversion of formerly softwood stands to a SH or even HS composition. Sprouting species in particular proliferate: both red maple as mentioned above and, in recent decades, American beech, which is affected by the beech bark disease. Due to widespread and heavy partial harvesting, this trend will continue. In addition, unlike vertically integrated forest products industries, the timberland investment organizations that own more and more commercial forestland in the Northeast have no long-term or wood production incentive to invest in early stand tending treatments such as hardwood control.

Thus, unlike our neighbors to the north who seek to maintain the hardwood component of many managed northern conifer (spruce–fir) mixedwoods, the challenge in the northeastern U.S. is to maintain or restore softwood composition. While this has been a focus of research in the southern portion of the Acadian Forest since the early 1900s (see work by U.S.D.A. Forest Service researchers M. Westveld and A. Hart, among others), recent declines in the regional softwood pulp market have reduced prices and demand for smaller-than-sawtimber softwoods. Yet, interest in ecological integrity, maintaining flexibility with regard to future markets, and the consistently high value of good-quality sawtimber spruce suggest that we would be well-served to constrain the abundance of hardwoods in low-site spruce–fir stands.

To that end, long-term research at the Penobscot Experimental Forest in Maine and elsewhere in New England and the Adirondacks of New York suggests that establishing and protecting advance softwood regeneration, controlling hardwoods through early stand tending with herbicides or brushsaws, and retaining vigorous softwood trees for seed during or after the regeneration period will increase the proportion of shade-tolerant softwoods. Those interested in maintaining a mixedwood composition, which confers both greater diversity and decreased budworm susceptibility (see work by D. MacLean in New Brunswick), can do this by using larger canopy openings and lower residual basal area during partial harvests.

Some examples of effective silvicultural treatments for varying compositions are as follows for the lowland spruce–fir type in northern New England:

Softwood:

- clearcutting, planting softwoods, conducting precommercial chemical or mechanical weeding;
- uniform shelterwood with removal of hardwoods during the preparatory cut, weeding, thinning (Figure 33);
- single-tree selection cutting on a short (5- to 10-year) cutting cycle with high residual basal area (approx. >100 ft^2/ac [23 m^2/ha] in trees >1 inch [2.54 cm] dbh) (Figure 34);

Mixedwood:

- clearcutting, planting softwoods and hardwoods;
- irregular shelterwood (Figure 35);
- group selection (gaps 2 tree-heights wide) or single-tree selection with a long (15- to 25-year) cutting cycle and low residual basal area (approx. <80 ft^2/ac [18 m^2/ha] in trees >1 inch [2.54 cm] dbh) (Figure 36);

Hardwood:

- clearcutting.

In addition, commonly applied exploitative cuttings such as fixed diameter-limit and commercial clearcutting (forms of high grading) result in stands with a greater proportion of hardwoods, with the amount of hardwood growing stock generally increasing with intensity and number of harvests (Figure 37).

Illustrations

When research by the U.S.D.A. Forest Service began in 1950 at the Penobscot Experimental Forest in Maine, all study stands had >80% softwood (S) composition. Results after 60 years for a range of treatments are shown in figures 33–37.

Figure 33. Uniform shelterwood spruce–fir (S) stand with precommercial (6 feet × 6 feet or 1.8 m × 1.8 m) and commercial (40% relative density removal) thinning. U.S.D.A. Forest Service photograph.

Figure 34. Softwood-dominated (S) spruce–fir single-tree selection stand in Maine (BA approx. 120 ft^2/ac [28 m^2/ha] in trees >1 inch [2.54 cm] dbh). U.S.D.A. Forest Service photograph.

Figure 35. Irregular shelterwood in a mixedwood spruce–fir–hardwood (SH) stand in Maine (Bob Seymour's "Acadian Femelschlag": irregular expanding gap shelterwood with reserves). U.S.D.A. Forest Service photograph.

Figure 36. Mixedwood spruce–fir–hardwood (SH) selection stand in Maine (BA approx. 80 ft²/ac [18 m²/ha]). U.S.D.A. Forest Service photograph.

Figure 37. Commercial clearcut (high-graded) mixedwood spruce–fir–hardwood (HS) stand in Maine. U.S.D.A. Forest Service photograph.

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