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silviculture

Managing Heterogeneous Stands Using a Multiple-Treatment Irregular Shelterwood Method

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In eastern Canada, past diameter-limit cutting left a legacy of low-density and heterogeneous hardwood stands. The complex stand structure and variable density hinders the application of uniform treatments for stand regeneration and rehabilitation. This article describes an innovative approach called the "multiple-treatment irregular shelterwood system." Two variants of the method are presented to achieve extended irregular shelterwood and continuous cover irregular shelterwood. The silvicultural prescription recognizes microstands that are grouped into microtypes based mainly on sapling stocking and tree canopy closure. For each microstand, harvesting of mature trees is allowed if the understory has sufficient stocking of saplings. If not, partial cutting and/or soil scarification is prescribed to promote regeneration. The design of the trail system and the sequence of entries are adapted for each irregular shelterwood variant. Results from two field trials show that this method is operationally feasible. Existing advance regeneration was adequately protected, and favorable microsite conditions were created when sufficient regeneration was lacking. Half of the volume of wood was harvested from test sites with no high grading of species composition or tree quality, while maintaining a high degree of structural heterogeneity.

Keywords: hardwood, silviculture, complex stands, mechanization, partial cutting, irregular shelterwood, rehabilitation, regeneration, *Betula alleghaniensis* Britt., *Acer saccharum* Marsh

Hardwood forests in eastern Canada and United States have a long history of partial harvesting, in which large trees with desirable attributes have been selectively removed without any specific measures to ensure proper stand regeneration and long-term sustained production of high-quality timber. From the early 20th century, practices known as diameter-limit cutting or selective cuttings were the norm (Bédard and Huot 2006). More often than not, these practices left a legacy of highly heterogeneous stands in terms of basal area, stocking of desirable regeneration, and quality of the residual growing stock and merchantable trees (Angers et al. 2005, Nyland 2006). Such stands commonly have a mosaic of condition classes. They have patches with abundant saplings or poles, others with little to no regeneration due to interfering plants or a closed canopy of dominant trees, and others having two strata with desirable regeneration overtopped by a partial canopy of large trees. Even 10–20 years after this type of harvest, the residual merchantable basal area and canopy cover are often low (typically averaging less than 16–18 m^2/ha and 50%, respectively).

Since the mid-1990s in the Province of Quebec, diameter-limit cutting has been progressively replaced by the selection system as the standard silviculture for uneven-aged hardwood stands (Bédard and Huot 2006). However, after one or more diameter-limit cuttings, previously harvested stands are often not suited to the application of the selection system in its classic sense, either because of the low basal area or lack of sufficient quality in the growing stock. In this case, silviculturists may be tempted to start over with a new stand, using uniform

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This article uses metric units; the applicable conversion factors are: centimeters (cm): 1 cm = 0.39 in.; meters (m): 1 m = 3.3 ft; square meters (m^2): 1 m^2 = 10.8 ft^2; cubic meters (m^3): 1 m^3 = 35.3 ft^3; millimeters (mm): 1 mm = 0.039 in.; hectares (ha): 1 ha = 2.47 ac.

shelterwood or other even-aged regeneration systems, such as strip clearcutting. However these are often unsatisfactory alternatives for the following reasons:

- Application of any single treatment across the entire stand results in areas not properly treated to promote regeneration because of high heterogeneity in advance regeneration density and irregular canopy cover.
- In uneven-aged stands, uniform treatments will cut down poles and small timber trees before they reach their full merchantable potential. This is a waste, unless these trees are of poor form or vigor or are undesirable species.
- The harvest of small merchantable trees will produce high volumes of pulpwood. In areas where demand for this type of roundwood is low or nonexistent, the treatment will probably not be profitable or cost-neutral and will require investments by the forest owner.

In addition, in regions where the natural disturbance regime favors uneven-aged stands, rehabilitation using even-aged silviculture systems will probably modify the structural and species diversity of the forest in a way that may be incompatible with ecosystem-based management objectives, requiring the maintenance of ecosystem integrity and the emulation of ecological processes (Seymour et al. 2002).

Irregular shelterwood systems are appealing alternatives for managing uneven-aged stands, filling the gap between even-aged systems and the balanced, selection system (Raymond et al. 2009). As for even-aged shelterwood methods, the aim of irregular shelterwood systems is to establish advance regeneration under the shade of mature trees, except that the overstory cover is retained for a longer and sometimes indefinite period of time. The irregular shelterwood system has many variants that can be classified into three groups, depending on the frequency, intensity, and spatial pattern of the partial cuttings: the expanding-gap irregular shelterwood, the continuous cover irregular shelterwood, and the extended irregular shelterwood. The first two variants aim to produce multicohort stands, whereas the last one produces a two-cohort stand. In contrast to the selection system, there is no intent to ensure a constant production of goods and services at the stand level (Nyland 2002). It is rather assumed that a sustained yield strategy is managed at the scale of the forest management unit.

Up to now, most practical applications of the irregular shelterwood system were developed using manual felling and cable skidding. Designing partial cutting systems adapted to mechanized operations is a challenging problem: the limited reach of the booms of the harvesting and skidding machines impose a denser trail network than in the case of manual felling and cable skidding. However, trails could be used as man-made gaps to establish new cohorts of trees within the stand, with potentially sufficient soil disturbance to favor small-seeded species such as yellow birch (*Betula alleghaniensis* Britt.), which benefit from soil scarification (Greene and Johnson 1998, Gastaldello et al. 2007, Prévost et al. 2010).

This article presents a methodology for designing irregular shelterwood prescriptions adapted to mechanized operations in stands with complex structures. It also presents results from two field trials, demonstrating the application of the system to rehabilitate low-density hardwood and mixedwood stands resulting from past exploitative cuttings. Short-term impacts on stand structure and yields and the operational feasibility of using the multiple-treatment method are presented.

Methods

The Multiple-Treatment Irregular Shelterwood Method

This method can be applied to implement either the continuous-cover or extended irregular shelterwood variants. Heterogeneous stands can be conceptualized as a mosaic of "microstands" or groups, and these can be regrouped into microtypes. With mechanized harvesting, microstands have a minimum area of approximately 300 m^2, corresponding to the area within the boom's reach of a typical harvester or feller-buncher. Each microstand is a "decision-unit," where the stand structure is assessed and the proper silviculture action is chosen based on options described by a predefined decision-tree (Figure 1). Many microstands of similar structure can form a larger patch, but decisions are required at every decision-unit. That approach circumvents any need to delineate the patches in the field before harvesting. The method has initially been designed to allow the operator of the harvesting machine to make a treatment decision for each decision-unit and adjust the partial harvest accordingly. However, the same approach can be applied using tree marking before the harvesting operation.

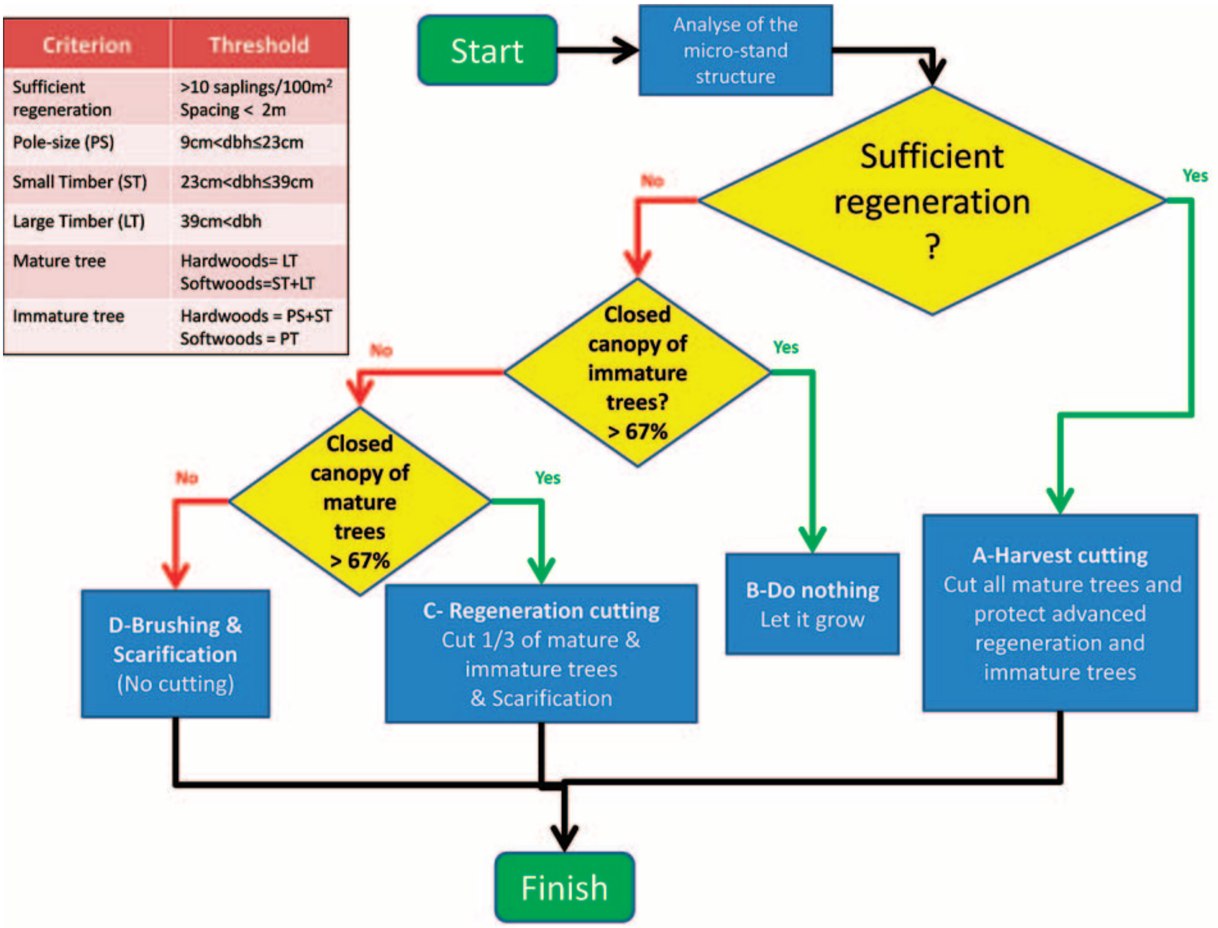
The number and frequency of entries, along with the spacing of the skid trails, are parameterized differently for the two irregular shelterwood variants. The decision-tree, the sequence of entries, and the skid trail layout are the three components of the prescription.

Step 1: Build a Decision-Tree Based on a Microtypology. We built our microtypology on developmental stages associated with the shelterwood regeneration method, based on the status of regeneration and the canopy closure of the overstory trees (Table 1). The treatment is focused on establishing advance regeneration before the eventual removal of the trees which have reached the target diameter for harvest. A dbh target value of 40 cm (measured at 1.3 m) was considered for hardwoods, whereas for softwoods (mostly spruce and fir) it was fixed at 24 cm.

Finding a sufficient number of advance saplings overtopped by a canopy of larger trees (microtype 1) allows the operator to harvest all the mature ones. Smaller trees are left to grow for future production. With uneven-aged stands, the small trees include trees of good growth potential (e.g., Kiernan et al. 2008) and quality and those can be managed into the future, whereas in even-aged stands, the small suppressed trees com-

Management and Policy Implications

This article presents an operational approach to harvest and regenerate highly heterogeneous hardwood stands. This method is applicable for rehabilitating degraded stands resulting from past exploitative partial cutting. The multiple-treatment approach allows the implementation of irregular shelterwood systems with mechanized operations in a cost-effective way. The harvest prescription is modulated to take into account the presence or absence of advanced regeneration of the desired species. This approach allows the application of an uneven-aged regime for stands that are generally not considered suitable for the selection cutting system.



Criterion	Threshold
Sufficient regeneration	>10 saplings/100m^2 Spacing < 2m
Pole-size (PS)	9cm<dbh≤23cm
Small Timber (ST)	23cm<dbh≤39cm
Large Timber (LT)	39cm<dbh
Mature tree	Hardwoods= LT Softwoods=ST+LT
Immature tree	Hardwoods = PS+ST Softwoods = PT

Figure 1. Decision-tree for multiple treatment irregular shelterwood systems.

monly have a low growth potential (Marquis 1991, Nyland et al 1993) and should be removed with the larger ones. At least for cutover shade-tolerant hardwood stands in Quebec, Majcen et al. (1984, 1985) found generally uneven-aged conditions.

For microstands with few saplings due to a closed overstory canopy (>66% of canopy closure, microtype 2), partial cutting is prescribed to increase light penetration to the forest floor. The cutting would remove one-third of the trees in all size classes, leaving a residual canopy cover of 33–66%. To favor yellow birch and spruce regeneration, spot scarification is recommended (see below).

In some other cases, the overstory canopy is sufficiently open (>67% canopy closure), but the understory has a dense shrub canopy (microtype 3), such as mountain maple (*Acer spicatum* Lamb.). Then no harvest is prescribed to keep seed trees in place and to maintain sufficient canopy. Brushing is prescribed to reduce the understory interference, followed by spot scarification.

Microtype 4 has a canopy of immature trees. In this case, the regeneration phase is postponed to allow the growing stock to reach a sexual and threshold size of maturity and to improve regeneration success. That also reduces the volume of pulpwood harvested, increasing the profitability of treatment.

Identification of each microtype relies on indicators and thresholds than can be visually assessed from the cab of a feller-buncher or by a tree marker. For our first trials, we used a maximum spacing of 4 m between saplings (1 cm ≤ dbh < 9 cm) to indicate adequate stocking of that size class (approximately >625 stems/ha). However, we believe a posteriori that a higher regeneration threshold may be justified; management guides for the selection system in northern hardwoods of the Upper Lake States suggest a sapling density of about 1,000–1,500 stems/ha (Eyre and Zillgitt 1953, Nyland 2002), whereas for the regular shelterwood system, Leak et al. (1987) suggest a minimum of 2,300 high-quality trees/ha with a dbh of 10 cm to reach a "B-level" relative density. Setting the maximal spacing threshold at 3 m would imply a minimal density of 1,000 saplings/ha.

Canopy closure is assessed visually based on three classes: closed (>66%), partial (33–66%), and open (<33%). The microtypology and associated thresholds should be validated for each stand through a pretreatment inventory and the subsequent analysis of data from the temporary sample plots. Additional instructions can be added to manage risk of future mortality and/or degradation of log quality over time, contingent on a consistent and reliable method to assess these risks and a set of visual cues that the tree marker or machine operator can use to identify high-risk trees.

Most hardwood harvest operations in Quebec are done late in the fall or during winter to avoid wood discoloration by fungus after cutting. In the snow-free period, sufficient soil disturbance is expected to favor birch and spruce regeneration, either due to movement of the machines on the trails or by spot scarification using the heel of the feller-buncher's harvesting head. However, with substantial snow cover, the level

Table 1. Micro-type characteristics and corresponding prescriptions for application of the multiple-treatment method in northern hardwoods.

Microtype		Definition	Prescription
Microtype 1: Mature and regenerated		• Sufficient sapling stock • Open to partial canopy of mature trees	1. Harvest all mature trees (dbh >40 cm) 2. Protect immature trees and saplings
Microtype 2: Mature, nonregenerated, and closed canopy		• Insufficient sapling stock • Closed canopy of mature trees	1. Harvest one-third of mature trees (dbh >40 cm) 2. Protect immature trees 3. Patch scarification if no seedling carpet
Microtype 3: Mature, nonregenerated, and open canopy		• Insufficient sapling stock • Dense shrub canopy • Open to partial canopy of mature trees	1. No harvest 2. Brushing and patch scarification
Microtype 4: Immature		• Canopy of immature trees	1. No harvest 2. No scarification

of soil disturbance will probably be insufficient: in this case a posteriori spot scarification is needed on the trails and between them using a midsize excavator.

Step 2: Design a Rational Trail System and a Sequence of Entries. Each of the two irregular shelterwood variants has its own sequence of entries and trail system. For both, a network of parallel trails is set perpendicular to the slope. Trail width should be 5–6 m (i.e., the distance between the tangent lines formed by the trees on each side of the trail), allowing acceptable levels of harvest damage, while ensuring sufficient partial shading for regeneration. On both sides of each trail, a 5-m-wide zone of intervention is used to decide what microtype surrounds the machine and to select a treatment option from the decision-tree. Between two zones of intervention, there is an intact zone within the intertrail space receiving no harvest or scarification. The width of this intact zone varies with the distance between the trails.

For both variants, two important parameters are considered: the average time required for producing a sapling from the seedling stage (T1) and the average time needed for a sapling to become a mature tree (T2). For the sake of the demonstration, we will use a T1 value of 10 years and T2 value of 110 years (for a target dbh of 40 cm).

For the continuous cover irregular shelterwood variant, we suggest extending the treatment over four entries, with a cutting cycle equal to one-fourth of the T1 + T2 value (i.e., 30 years in our example). In this case, trails are set out every 30 m. At the first entry, this means that the proportion of stand area-occupied trail and zones of interventions will be 17–20% and 30%, respectively. Thirty years later, trails from Entry No. 2 are established between the first set of trails, in the middle of the previous intact zone. At Year 60, trails from Entry No. 3 are located on the right side of the Trail Set No. 2, in between Trail Sets No. 1 and 2. At Year 90, the last set of trails is located on the left side of Trail Set No. 2. After 120 years, trees established in the first trail set should have reached sufficient size to support another entry. Over the whole cycle, we expect to establish four new cohorts in trails on approximately 70–80% of the stand area. This trail system can be visualized in Meek et al. (2012).

For the extended irregular shelterwood variant, the objective is to have two entries, each treating 50% of the stand area, with the entries separated by sufficient time for an adequate sapling bank to develop (T1 = 10–15 years in our example) and for the immature residual trees to reach their sexual maturity. The two entries are then followed by a growth period of about 110 years (T2) without any further regeneration treatment. In this case, the trail spacing is 20 m (Meek and Lussier 2008). Trails for the second entry are laid down in the intact zone between trails from the previous entry. After the second entry, we should have established two new cohorts on the trails on 50% of the stand area, along with advance regeneration and pole-size trees on the other 50%.

Field Trials

Study Site. Application of an extended irregular shelterwood using the multiple treatment method was tested in 2004–2005 in two blocks: one site located near the Franchère Lake (46°50′16″ N, 75°30′13″ W), and another near Lake Major (46°44′45″ N, 74°59′41′ W), near Mont-Laurier (Quebec, Canada). The Franchère trial involved 230 ha from November 2004 to December 2005. At both sites, the prescription was applied without tree marking. Harvest machine operators were trained to identify microstand types and monitored as they applied the decision-tree. The Franchère site was primarily used to work out the prescription-making procedures. The Lake Major trial covered 80 ha in June 2005 to develop and test a feedback procedure for quality control and continuous improvement.

Both sites are representative of typical problematic stand conditions resulting from past exploitative cuts: low basal area prevents the application of selection cuttings in the short-term. Both stands show a highly variable canopy closure and the presence of acceptable regeneration stock (Table 2).

Table 2. Confidence intervals for the mean value of descriptors of the merchantable stand, before and after treatment, at two test sites.

	Franchère	Major
Density (stems/ha)		
Initial	372.4–457.0b	508.2–628.2a
Residual	263.5–340.4c	322.9–453.3bc
BA (m^3/ha)		
Initial	17.9–20.1a	18.1–21.3a
Residual	10.1–11.8b	10.7–13.7b
Volume (m^3/ha)		
Initial	118.4–136.0a	105.9–127.3a
Residual	64.1–75.3b	59.1–76.8b
Mean volume (m^3/tree)		
Initial	0.389–0.478a	0.226–0.309b
Residual	0.346–0.442a	0.239–0.376ab
Crown closure (%)		
Initial	59.5–67.8a	64.5–74.7a
Residual	27.8–36.4c	48.7–60.7b
Species composition (% BA)		
Yellow birch		
Initial	29.6–36.3a	33.7–43.8a
Residual	30.1–37.3a	31.2–42.1a
Sugar maple		
Initial	16.7–25.0a	3.9–10.1b
Residual	17.8–26.9a	4–11.8b
Red maple		
Initial	7.2–10.7a	7.5–14.8a
Residual	7.7–12.6a	8.8–18.7a
White birch		
Initial	9.7–14.8a	6.3–13.8a
Residual	9.6–15.4a	5.5–14.4a
Balsam fir		
Initial	7.8–11.6b	12.7–21.4a
Residual	6.3–10.4b	10.6–20.6a
Quality grade (% BA)		
Sawlog		
Initial	59.2–65.0a	61.1–70.1a
Residual	63.4–70.3a	58.7–70.4a
Pulp		
Initial	35.2–40.9a	29.5–38.3a
Residual	29.8–36.7a	29.1–40.4a
Risk grade (% BA)		
Low		
Initial	57.4–62.5a	60.0–68.3a
Residual	63.1–69.7a	63.6–72.5a
High		
Initial	37.4–42.6a	30.8–39.1a
Residual	30.2–36.7a	26.1–35.3a
Postharvest injury (% density)	1.5–3.5a	1.1–4.0a

Significant differences before and after treatment and among sites are indicated by different letters. BA, basal area.

The region is dominated by rolling terrain with some steep and/or irregular slopes, and an average elevation of 288 m (amplitude 90 m). Glacial till comprises the predominant superficial deposit, at often <1 m thickness. Annual average temperature is between 2.5 and 5° C, and total precipitation is about 900–1,000 mm (25–30% in snow) (Robitaille and Saucier 1998).

The sites are located at the northern limit of the hardwood region (Robitaille and Saucier 1998). In stands classified as "shade-tolerant hardwoods," yellow birch and sugar maple (*Acer saccharum* Marsh.) dominate the growing stock, but sugar maple is close to the northern limit of its natural range at these sites. The Lake Major site showed a higher content in softwoods, mostly balsam fir (*Abies balsamea* [L.] Mill.) and red spruce (*Picea rubens* Sarg.). Severe natural disturbances are not common, and uneven-aged stands are most common across the landscape. Both sites were logged by diameter-limit or selective cutting in the past. More detailed stand descriptions are presented below with results of the experiment.

At the Franchère site, soil scarification was done with the feller-buncher at the same time as the partial cutting. At the Lake Major site, spot scarification was done on the trails and in the zone of intervention 3 years later (2008) using a midsize excavator, but only where the regeneration was deficient. Scarification removed the organic layer from a 1 × 2 m spot without digging into the mineral horizons.

In this region, yellow birch is the most valuable species for the production of lumber and veneer. Maple has a high proportion of dark wood color and poor form, reducing its value for lumber and veneer. The area has limited and fluctuating markets for pulpwood and fuelwood.

For these first trials, the maximum dbh threshold for technical maturity was set at 30 cm for hardwoods. Based on an initial visual reconnaissance, the decision-tree only included microtypes 1, 2, and 3. In addition, for microtype 2, the prescription was to cut one-third of the overstory trees and protect the immature ones. After these first trials, the prescription was modified as presented in Table 1 to include a one-third cut in all size classes, to better brighten the forest floor.

Impact on Stand Structure and Yield. A total of 227 and 78 variable-radius plots (basal area factor 2) were randomly installed at the Franchère and the Lake Major sites, respectively. Plots were set out before the treatment to define the requisite rehabilitation options and later to assess the immediate impacts of the treatments on stand structure and yield. Tree species, dbh class (2 cm), stem quality, and risk grades were evaluated for all live trees >9 cm dbh. Based on procedures of the Quebec Ministry of Natural Resources (Merette 2006), trees were divided in two quality classes: "sawlog trees" that had at least one acceptable sawlog of 2.5 m in length within the whole tree and "pulpwood" for the other trees. Pole-sized trees that did not meet the minimal size for sawlogs but that otherwise could potentially produce them in the future were also classified as sawlog trees. Risks of tree mortality and degradation of wood quality were assessed by the MSCR classification used in the Province of Quebec (Boulet 2005). For that assessment, M and S classes (not growing and poor growing stock) were grouped together; we did the same with trees in the C and R classes (acceptable and premium growing stock). Sample trees were numbered with permanent paint. After the logging, harvested and injured trees were tallied. The juxtaposition of all sample trees relative to the trail system was recorded, depending on their position in the trails, in the zone of intervention, or in the intact zone.

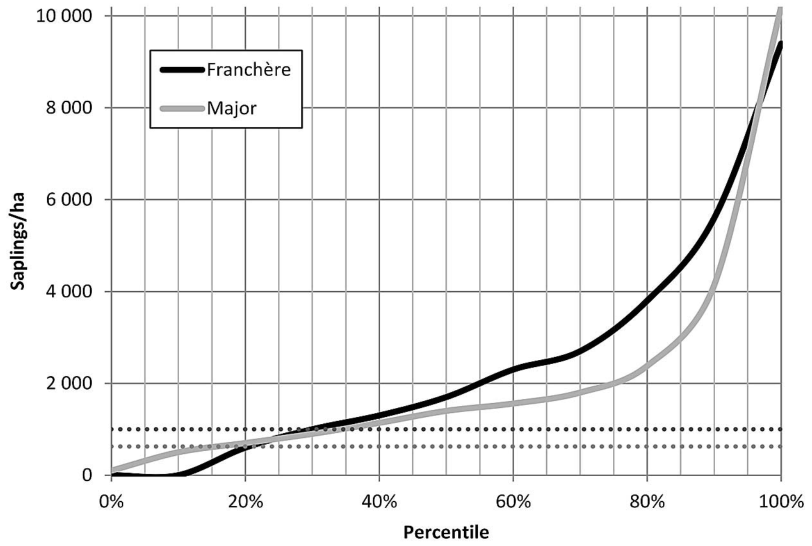


Figure 2. Percentile distribution of sapling density in microstands at the two trial sites (the dashed lines represent the 625 and 1,000 saplings/ha thresholds for judging the adequacy of regeneration stocking).

At the center of each prism point we used a 100-m^2 circular plot to record the number of saplings per species group (yellow birch, other hardwoods, and softwoods) and the relative cover of shrubs and seedlings (per species group). For each plot, the number of seed trees was estimated by counting trees less than two tree heights from the plot center. Ocular estimation of canopy closure (trees with dbh >9 cm) was done with a hemispherical lens.

These variables were measured again immediately after the treatment. At the same time, we evaluated the percentage of plot surface with disturbed soil (scarification and rutting) and the position of each plot within the trail (i.e., in a trail, in the zone of intervention, or in the intact zone).

The impact of the treatment on medium-scale structural diversity was measured using the coefficient of variation among sampled plots of three metrics: merchantable basal area (m^2/ha), average tree volume (dm^3), and sapling density (trees/ha).

Feedback Procedure. In the case in which there is no tree-marking, the multiple-treatment method implies a more complex set of tasks for the operator of a feller-buncher, relative to cutting marked trees. To give timely and frequent feedback to the operator, a supplemental set of "feedback plots" were established by the supervisor of the harvest operations. A cluster of 10 of these plots were established on a daily basis after treatment. Each cluster comprised 10 pairs of 5 × 10 m rectangular plots along each side of a trail, within the zone of intervention (see Figure 2 in Meek and Lussier 2008). For each plot, the supervisor counts the saplings and the number of tree and stumps to estimate the harvest intensity. The percentage of plots for which the operator's decision is congruent with the prescription is discussed, along with ways to refine decisions. In addition, for each group of plots the supervisor adds one or two transects perpendicular to the trail to measure trail width and intertrail spacing.

Statistical Analysis

Pre- and posttreatment stand conditions were compared using confidence intervals for each variable. For each variable, confidence intervals for a probability of 95% (CI95%) were estimated by bootstrapping, using the "boot" package from R (Canty and Ripley 2012). The analysis was based on 1,000 subsamples stratified by site. Confidence intervals were calculated using the bias-corrected and accelerated (BCa) method (Efron 1981). Differences between sites and before and after treatment were considered nonsignificant when the confidence intervals overlapped. The initial diameter distributions of the two sites were compared using a χ^2 test.

Results and Discussion

Frequency of Microtypes and Application of the Prescription

The percentile distribution of sapling density before treatment shows that only a

Table 3. Confidence intervals for the mean value of descriptors of the regeneration, before and after treatment, at two test sites.

	Franchère	Major
No. of seed trees per plot		
Yellow birch		
Initial	5.4–6.9ab	6.8–8.8a
Residual	4.1–5.4b	3.9–5.4b
Softwoods		
Initial	2.8–4.3ab	4.1–6.0a
Residual	1.3–2.1c	2.2–3.6b
Sapling density (stems/ha)		
Yellow birch		
Initial	388.6–762.1a	267.3–436.5a
Residual	235.5–452.4ab	118.2–256.1b
Other hardwoods		
Initial	927.2–1418.3a	376.1–629.9b
Residual	560.3–857.5a	133.8–296.2c
Softwoods		
Initial	552.5–848.7a	811.2–1585.9a
Residual	324.9–571.4a	371.4–958.6a
Total		
Initial	2,046.8–2,705.6a	1,562.3–2,522.5a
Residual	1,214.7–1,684.6b	665.1–1,315.9b
Seedling stocking (%)		
Yellow birch		
Initial	0.3–1.1a	0.3–0.7a
Residual	0.3–0.7a	0.1–0.5a
Other hardwoods		
Initial	12.1–19.0a	5.7–12.3a
Residual	8.9–14.2a	1.4–3.2b
Softwoods		
Initial	4.1–6.6a	6.0–10.7a
Residual	3.4–5.8a	2.4–5.5a
Shrub cover (%)		
Initial	21.6–27.9a	26.5–37.5a
Residual	10.5–15.9b	9.9–17.1b

Significant differences before and after treatment and among sites are indicated by different letters.

Table 4. Concordance between the silviculture prescription and the operator's decision, based on the operational control plots at the Lake Major site.

	Operator's decision		
Prescription	Partial harvest	Total harvest	Total
	(%)		
Partial harvest	31	16	48
Total harvest	30	22	52
Total	62	38	100

N = 83.

small fraction of the microstands had an insufficient sapling density: at Franchère, 22.7% of the plots had 625 saplings/ha or less, whereas at Lake Major this threshold was found on 12.2% of the plots (Figure 2). No significant difference in the mean number of saplings was found between the two sites (Table 3). There was also no significant statistical differences in microtype frequency: the overlapping confidence intervals of the frequency of microtype 1 (mature and regenerated) were 70–83% at the Franchère site and 75–92% at the Lake Major site. Mature, nonregenerated microstands with a closed canopy (microtype 2) accounted for 5–14% at the Franchère site and 3–14% at the Lake Major site. The frequency of mature nonregenerated microstands with an open canopy was 11–22% and 1–10%, respectively, for the Franchère and Lake Major sites.

Based on operational feedback plots, the level of concordance between the prescription and the operator's decision was 53% at the Lake Major site (sum of diagonal values in Table 4). The largest departure occurred in cases in which the operator chose to do a partial harvest of mature trees even when the advance regeneration was sufficient for overstory removal. That made the treatment more conservative than we considered necessary. This was actually observed at both sites: often operators preferred to keep more mature trees than required.

Even the supervisors seemed conservative in their evaluations of sapling abundance. They recommended overstory removal in only 52% of the cases (Table 4), which is out of the confidence interval of the frequency of microtype 1 for the Lake Major site (75–92%).

Compliance by operators with the intended prescription has significantly improved over time. In 2010, we observed an average concordance of 88% based on treating 24 blocks totaling 974 ha (Allard and Gauthier 2010). In general, operators found the feedback highly valuable in helping them to improve the quality of their work. Our findings highlight the importance of adequate feedback and allocating sufficient time to train the operators in making appropriate judgments to ensure a successful treatment.

In the Lake Major site, operators using an excavator for the spot scarification complied with the prescription 93% of the time, based on the operational feedback plots (Houle-Bellerive 2009).

Impact on Merchantable Trees

Before treatment, diameter distribution did not differ significantly between the two sites (Figure 3). The confidence interval for the average basal area and merchantable volume was statistically comparable for both sites, ranging, respectively, from 18–21 to 106–136 m^3/ha (Table 2). The treatment significantly reduced basal area by 40% and tree density by 30%, as shown by the nonoverlapping confidence intervals. Even if the prescription tended to harvest larger-than-average trees, there was no significant impact on average residual tree volume in both sites (Table 2).

The CI95% for residual basal area and canopy cover were, respectively, 10–13 m^2/ha and 28–61%, which are in the range of recommended values for shelterwood treatments. Trees cut for the skid trail counted for 17–24% of the initial basal area, which corresponds to about one-third of the harvested basal area. Only 1–4% of the residual trees had logging injuries, as is typical for bole skidding along straight 5-m wide trails (Table 2).

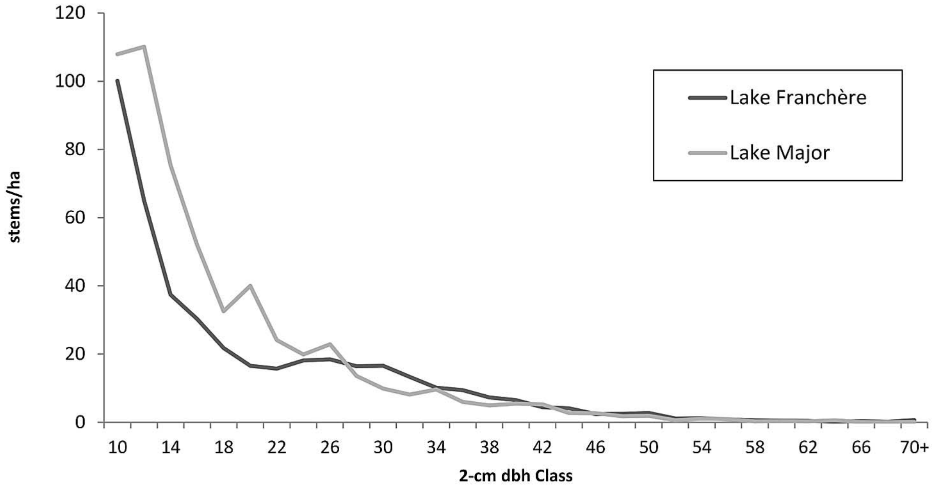


Figure 3. Diameter distributions at the two trial sites in Quebec.

Table 5. Confidence intervals for the coefficient of variation of basal area, average tree volume, and sapling density, before and after treatment, at two test sites.

	Franchère	Major
Basal area		
Initial	36.4–45.2a	31.4–47.7a
Residual	45.1–57.3ab	48.5–65.9b
Mean stem volume		
Initial	57.9–73.1a	53.1–99.9ab
Residual	71.2–88.0ab	82.5–120.0b
Sapling density		
Initial	85.8–105.2a	87.6–120.9a
Residual	93.3–119.1a	123.2–199.7b

Significant differences before and after treatment and among sites are indicated by different letters.

From the initial basal area, 42–50% of logging injuries were located in zones of intervention, whereas 17–20% were in intact zones.

In both sites, yellow birch was the prominent species before treatment (30–44%). Trees of sawlog grade comprised 59–70% of the hardwood basal area, with those of low risk for mortality and of acceptable quality (class CR) accounting for 57–68%. Overall, the treatment had a neutral effect on stand composition, quality, and risk level, because no significant differences were found in either site (Table 2).

Impact on Regeneration

Total sapling density was significantly reduced 40% by the treatment (Table 3). Activity along the skid trails accounted for 17–24% of sapling mortality, with the remainder lost in the zone of intervention. Overall, residual sapling density remains satisfactory in both sites, at 665–1,685 trees/ha. However, even after treatment, the proportion of yellow birch is significantly lower in the sapling size-class (18–28% at the Franchère site and 17% at the Major site) than among the merchantable size classes (30–46% at the Franchère site and 34–48% at the Major site). The shrub layer was also reduced in the same proportion as the sapling stock, with a residual cover of 10–17% in both sites (Table 3).

Maintenance of yellow birch production over time relies on the installation of new seedlings. Before treatment, overall seedling stocking was low (<20%) (Table 3). The treatment did not affect yellow birch and softwood seedling abundance but reduced significantly that of other hardwoods at the Major site, whereas no difference was noted at the Franchère site. The microsite conditions after treatment are suitable for establishment of new birch regeneration: the residual number of seed trees of desirable species is 4–5 per microsite for yellow birch; and residual canopy closure is 36–43% (Table 2), considered favorable for midtolerant species. Soil disturbance was limited, with deliberate scarification on only 1.1–2.3% of the sampled plots at the Major site. "Accidental scarification" caused by machine operation covered an additional 1.0–2.6% of the surface. Exposure of the bedrock (a potential issue for scarification on thin soils) is not worrisome in this case (3.7–6.5%).

Further monitoring will evaluate regeneration success in skid trails. By the end of the two entries using this system, based on the extended irregular shelterwood variant, we expect the establishment of two new tree cohorts, in addition to the advance regeneration already present on the site before treatment. This should perpetuate the uneven-aged nature of the treated stands.

Impact on Structural Diversity

Stand heterogeneity was quantified based on the SD of three metrics: basal area, mean tree volume, and sapling density. Confidence intervals show that the treatment resulted in a small but significant reduction in the variability of basal area and sapling density at the Major site but not at the Franchère site (Table 5). No significant differences were found for the average tree volume. The treatment did not appreciably homogenize stand structure, but it did enhance the potential to regenerate desirable species. In addition, it upgraded the growing stock in partially cut microstands.

Further Work: Microtypology and Prescription

The initial typology seemed sufficient to address the rehabilitation needs of the study sites. Other cases may require adjustment of the typology, as well as the thresholds that guide decisions about what prescription to apply. Further work should be performed to explore a broader range of microstand structures that characterize other heterogeneous hardwood stands. Additional modeling analysis is needed to validate the a priori estimation of the cutting cycles.

The trials presented here show that is it possible to assign tree selection to the operator of the harvest machine without a fear of degrading the stand, as long as an adequate feedback system is in place. Cimon-Morin et al. (2010) found no statistical difference in residual stand structure between a marked-tree operation and operator-made tree selection in a similar uneven-aged silviculture system with a rather straightforward prescription. Compared with mechanized selection cutting (the reference system in the study area), Meek and Lussier (2008) observed a significant increase in harvest productivity and a reduction in harvest cost proportional to the average size of harvested trees (for values over 500 dm^3). Further trials are needed to improve cost and productivity estimations.

Conclusion

We present a rational method for implementing two variants of the irregular shelterwood system. The multiple-treatment method bases the silvicultural treatment on the variability of stand structure and allows an integration of a pertinent regeneration method with harvesting in complex stands. Our trials show that the multiple-treatment irregular shelterwood system is a feasible alternative for managing highly heterogeneous hardwood stands that do not fit the usual requirements for the application of uniform treatments. Short-term results show that the advance regeneration was adequately protected and that favorable microsite conditions were created where advance regeneration was insufficient. Harvesting removed a significant volume of valuable trees without high grading of the species composition or residual tree quality. Further research must validate the use of this method in a wider range of stand conditions and evaluate the long-term impact on stand structure and volume yields. This silviculture method has great potential for managing irregular stands, particularly where a multiage condition is desired, but without necessarily striving for even-flow sustained yield in a stand.

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