Effects of selective cuts on the mycorrhizae of regenerating *Betula alleghaniensis* and *Acer saccharum* seedlings in two Quebec mixed deciduous forests

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Abstract: The mycorrhizae of younger (2- to 3-year-old) and older (5- to 12-year-old) yellow birch (*Betula alleghaniensis* Britton) and sugar maple (*Acer saccharum* Marsh.) seedlings and saplings were recorded from naturally regenerating plants in gaps created by selective cuts and compared with those of plants of comparable age growing in the undisturbed forest. The levels of ectomycorrhizal colonization and the diversity of ectomycorrhizal fungi (based on morphotyping) were recorded for yellow birch and the levels of colonization and the abundance of arbuscules, vesicles, and coils were reported for the vesicular–arbuscular mycorrhizae of sugar maples. Selective cutting had no negative effect on the mycorrhizal community structure of yellow birch and sugar maple. This may be because of the quick regeneration of the mycorrhizal hosts coupled with the minor levels of soil disruption and relatively small gap size at the study sites. Greater colonization levels in the gaps versus uncut areas were observed in the 2- to 3-year-old maples but not in the 2- to 3-year-old birch seedlings. The types of ectomycorrhizal fungi colonizing the roots of birch seedlings from the gaps did not differ from those in the uncut forest areas.

Résumé : Les mycorhizes de jeunes (2–3 ans) et de vieux (5–12 ans) semis et gaules de bouleau jaune (*Betula alleghaniensis* Britton) et d'érable à sucre (*Acer saccharum* Marsh.) ont été dénombrés chez la régénération naturelle dans des trouées dues à des coupes sélectives et comparées à celles de plants d'âge comparable croissant dans la forêt non perturbée. Le degré de colonisation ectomycorhizienne et la diversité des champignons ectomycorhiziens (basée sur le type morphologique) ont été notés chez le bouleau jaune. Chez l'érable à sucre, le degré de colonisation et l'abondance des arbuscules, des vésicules et des vrilles ont été notés pour les mycorhizes à vésicules et arbuscules. La coupe sélective n'a pas eu d'effet sur la structure de la communauté mycorhizienne du bouleau jaune et de l'érable à sucre. Cela pourrait être dû à la régénération rapide des hôtes combinée à une perturbation mineure du sol et à la relativement petite dimension des trouées dans les sites étudiés. Un degré de colonisation plus élevé a été observé dans les trouées comparativement aux endroits non coupés chez les semis d'érable de 2 à 3 ans mais non chez les semis de bouleau du même âge. Les types de champignons mycorhiziens qui colonisent les racines des semis de bouleau dans les trouées sont les mêmes que ceux qui sont présents dans la forêt non coupée.

[Traduit par la Rédaction]

Introduction

In Quebec the selective cutting technique is used in many yellow birch (*Betula alleghaniensis* Britton) – sugar maple (*Acer saccharum* Marsh.) forests to regenerate a variety of shade-tolerant to mid-shade-tolerant tree species. Larger gaps are created to favor the growth and survival of yellow birch, a mid-shade-tolerant species, while smaller ones are

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created to favor the growth and survival of the more shade-tolerant sugar maple. Both species regenerate well in the understory following selective cutting, especially when some soil disturbance is created by the logging operation (Majcen and Richard 1992). However, the long-term survival of yellow birch is believed to be associated with the presence of larger gaps (Majcen and Richard 1992).

Mycorrhizal fungi colonize the roots of most plants found in deciduous forests, where they play an important role by enhancing nutrient uptake, drought tolerance, and resistance to pathogens (Smith and Read 1997). When host plants are removed, mycorrhizal fungi can be affected in different ways. Some studies have shown that overstory removals may not drastically alter mycorrhizal species diversity and colonization rates (Visser et al. 1998), whereas others have found lower colonization rates on seedlings collected from clearcuts than those collected from uncut forest (Harvey et al. 1980; Parke et al. 1984). Kranabetter and Wylie (1998), reported a gradual decrease in fungal diversity from the edge of a cut to the interior of the gap. Canopy openings, through changing the microhabitat, may also affect the mycorrhizal

community, as different fungi have different physiological requirements, environmental tolerances, and microhabitat preferences. The resulting environmental changes may result in the replacement of one mycorrhizal fungal species by another (Perry et al. 1989).

The effects of canopy gaps created by selective cutting on the mycorrhizal community in mixed deciduous forests of Quebec have yet to be examined. The dominant trees, yellow birch and sugar maple, have different mycorrhizal systems, which could respond in very different ways. Sugar maples are colonized by vesicular–arbuscular mycorrhizal (VAM) fungi, and to fully assess the impact of environmental changes, both colonization levels and the various fungal structures present in the roots need to be investigated. Past studies have shown that there is a correlation between the colonization rates by vesicles, coils, and arbuscules within the cells and the environment in which the plants are growing. In sugar maples, stressed by either low soil pH, high ultraviolet-B or high ozone levels, colonization by vesicles increases, while the numbers of arbuscules decreases (Costanzo 1999; Duckmanton and Widden 1994; Klironomos 1995; Klironomos and Allen 1995). Yellow birch are colonized by ectomycorrhizal (ECM) fungi. To assess the quality of an ECM association, overall colonization levels are needed along with a measure of the fungal diversity present on the plant roots (Meier 1991), as changes in colonization levels or community composition both have the potential to affect the function of the mycorrhizal system. Changes may be subtle, however, and the quantification of ECM fungi on the root tips alone may not show changes in community structure. Changes in ECM fungal diversity and community composition in response to changing environments have been reported in many studies (Dighton and Skeffinton 1987; Godbold and Berntson 1997; Meier 1991; Qui et al. 1993; Saikkonen et al. 1999).

The responses of mycorrhizae on sugar maple and yellow birch to selective cutting are unknown and information on the ECM fungal community colonizing birch roots in Quebec forests is scarce. Therefore, this study was undertaken in two similar forest sites, which differed in the time since selective cuts had been performed, with the following objectives: (*i*) to assess, throughout the growing season, the effects of selective cutting and seedling age on the mycorrhizal status of sugar maple and yellow birch; (*ii*) to characterize the community of ECM fungi colonizing the roots of the birch seedlings growing in gaps and in uncut areas, using morphological methods; and (*iii*) to compare responses between recent and older cuts.

Materials and methods

Study sites

Seedlings were collected from two mixed deciduous forests in central Quebec. One site is in the Réserve faunique de Portneuf in Rivière à Pierre, Que. (47°04′N, 72°15′W), where sugar maple and yellow birch make up 75% of the vegetation cover. Other common VAM trees include red maple (*Acer rubrum* L.); mountain maple (*Acer spicatum* Lam.); and, in the understory, striped maple (*Acer pennsylvanicum* L.), pin cherry (*Prunus pensylvanica*), and Canada yew (*Taxus canadensis* Marsh.). Other common

ECM trees include American beech (*Fagus grandifolia* Ehrh.), red pine (*Picea rubens* Sarg.), and balsam fir (*Abies balsamea* (L.) Mill.). The site is characterized by an undifferentiated till approximately 1 m deep. The soil is an Orthic Humo-Ferric Podzol with an average pH of 5.57 in the organic horizons (Ricard 1999). The elevation ranges between 320 and 400 m (Ricard 1999), and because of the similar geography and close location, the climate is similar to that at Duchesnay (described below).

The second site is located at the Station Forestière in Duchesnay, Que. (46°55′N, 71°00′W). The elevation ranges from 200 to 300 m, mean annual precipitation is 1220 mm, and mean minimum and maximum temperatures range from –12°C in January to 28°C in July. The canopy is dominated by sugar maple, yellow birch, and American beech. The dominant understory vegetation includes Canada yew, striped maple, and some mountain maple. The soil is a Humo-Ferric Podzol on a deep undifferentiated till with an average pH of 4.94 in the organic horizons (Ricard 1999).

Sample collection

At Duchesnay, sampling took place at two locations. At one location, gaps were cut in the fall of 1988, and at the second location, gaps were created in the fall of 1994, resulting in gaps aged 3 and 9 years. At both locations, saplings were collected from gaps of two sizes: small gaps, which were natural openings of 0–50 m^2, and larger gaps of 50–250 m^2. The ages of these selected saplings were estimated to vary between 5 and 12 years. In November 1997 and October 1998, five sugar maple, and five yellow birch saplings were collected from gaps of two sizes (i.e., small gaps of 0–50 m^2 and large gaps of 50–250 m^2) from both locations. A total of 20 sugar maples and 20 yellow birch were collected for these 2 months. In April, June, July, August, and September 1998, three saplings of each species were collected from the different-sized gaps at the two locations, for a total of 12 of each species. A total of 100 trees of each species were sampled at this site.

In both gap types (i.e., small gaps of 0–50 m^2, and large gaps of 50–250 m^2), saplings of ~1 m in height were selected. Because of sapling mortality, we had to reduce our sampling to three saplings per treatment for June to September, but five saplings were selected for the month of October. At all sampling times, the whole sapling was removed from the soil with a shovel, leaving soil around the roots to prevent dessication. Saplings were left in a bag and stored at 4°C until they were returned to the laboratory. In the laboratory, the soil was washed from the roots and a representative sample of each root system was collected for mycorrhizal analysis.

At Rivière à Pierre, seedlings were collected from nine oval-shaped 1000-m^2 gaps that had been cut in November and December 1996. Sampling took place in June, August, and October 1998. In June and August 1998, three 2- to 3-year-old sugar maple and three 2-year-old yellow birch seedlings were collected from within each gap and from the uncut areas surrounding each gap, for a total of 108 seedlings for each month. In October, five 2- to 3-year-old sugar maple and five 2-year-old yellow birch seedlings were collected from each gap and from the uncut areas surrounding each gap for a total of 180 seedlings. At each sampling, a transect

was drawn from the edge of the gap to the centre, and seedlings of each species were collected along this line. The location of each seedling from the edge of the cut was recorded. Seedlings of the same age were also collected in the uncut areas surrounding each gap and were selected around the circumference, at least 5 m away from the edge of the gap. Again, because of the lack of seedlings available, sampling from each gap was kept to three seedlings per treatment (inside and outside the gap) for the first two sampling dates and increased to five for the month of October.

Light measurements

At both sites, light measurements were made under overcast sky conditions using to the method of Parent and Messier (1996). The measurements in the forest were obtained with a hand-held LI-190 point quantum sensor (LI-COR, Inc., Lincoln, Nebr.). Continuous light measurements of an above-canopy photosynthetic photon flux density (PPDF) from an adjacent opening were recorded using an LI-1000 data logger (LI-COR, Inc.). At Rivière à Pierre the PPDF was measured in August 1998 in each of the nine 1000-m^2 gaps and in the surrounding uncut areas. The light measurements were taken at a height of 20 cm above the forest floor. In Duchesnay, the light measurements were taken in September 1999. When the seedlings were sampled the previous year, a stake with each seedling's height was left at the exact spot from which they were taken. The following year, the light measurements were taken at each seedling's height.

Staining and quantification of VAM structures in the sugar maple roots

From the larger seedlings collected at Duchesnay, a portion of the fine branches of the root system were preserved in formalin – alcohol – acetic acid (FAA) at room temperature for a minimum of 24 h. Complete root systems of the younger seedlings collected at Rivière à Pierre were preserved in FAA solution. The preserved roots were placed separately in OmniSette® Tissue Cassettes (Fisher Scientific, Pittsburgh, Pa.) and cleared by autoclaving for 35 min at 103.4 kPa in 10% KOH. The autoclave step was repeated three times, changing the 10% KOH solution each time. The roots were then gently rinsed with tap water, bleached with 30% hydrogen peroxide for 1 h, rinsed again with tap water, acidified in 15% HCl for 15 min, and stained in 0.15% chorazol black E at 90°C for 12–15 min. The roots were then left overnight in a destaining solution of 50% glycerol, mounted on slides in glycerine jelly, and squashed with a cover slip (Widden 2001). The VAM fungi were examined using a Nikon Optiphot differential interference contrast (DIC) microscope at a magnification of either 200× or 400×. The colonization rate for each root sample was obtained using the magnified grid-intersect method (McGonigle et al. 1990). One hundred intersects were evaluated, and at each intersect the occurrence of arbuscules, vesicles, and coils was recorded. For each fungal structure, the colonization rate was determined by counting the number of intersects in which it was present. Total colonization levels were obtained by counting all intersects that had at least one fungal structure present.

Observation and quantification of the ECM on the birch roots

A portion of each birch root system (~1–2 g) was sampled for all yellow birch collected from the Duchesnay site. Roots free of soil were placed in distilled water in plastic vials and stored for a maximum of 48 h before being quantified and morphotyped. Roots were cut into ~3- to 5-cm pieces and laid out in an INTEGRID™ Petri dish (Becton Dickson Labware, Lincoln Park, N.J.). The quantification of the ECM was performed using a Wild Heerburrg dissecting microscope with magnifications of 128–800×. Percent colonization was obtained by a grid line intersect method where 100 root tips for each sample were analyzed for the presence or absence of ECM. The distinction between ECM and noncolonized root tips was based on the presence or absence of a mantle. Each mycorrhizal tip was assigned to a mycorrhizal morphotype on the basis of macroscopic (color, branching pattern, texture, external hyphae, tip shape) and microscopic (mantle type, the presence and types of cystidia, the presence or absence of clamp connections) features (Goodman et al. 1998).

Whole root systems of the seedlings from Rivière à Pierre were evaluated for ECM colonization. When root systems were too large (i.e., over 500 root tips), the root branches were cut into ~2-cm pieces before being placed in the dish. Fifteen randomly selected squares were chosen, and the ECM on all root tips present in the 15 squares were quantified and the morphotypes recorded.

Statistical analysis

All statistical analyses were performed using SPSS software (Norusis 1997). For the data collected from the sugar maples at both sites (Rivière à Pierre: uncut forest $n = 99$, gaps $n = 99$, Duchesnay: small gaps $n = 50$, large gaps $n = 50$), a t test was used to detect differences in colonization levels between treatments within a single sampling month. When the data did not fit the normal distribution an arcsine transformation was performed. A Tukey HSD test ($p < 0.05$) was used to detect any treatment differences. A two-way ANOVA was used to detect any overall effects of date and treatment on colonization levels.

The data for ECM colonization levels on the birch roots at Rivière à Pierre (uncut forest $n = 99$, gaps $n = 99$) were not normally distributed; thus, nonparametric tests (Mann Whitney U tests, Zar 1984) were used to investigate any differences in colonization between treatments within each sampling month. Treatment differences for ECM colonization of the birch at Duchesnay (small gaps $n = 50$, large gaps $n = 50$), within a sampling month were analyzed using a t test. A two-way ANOVA was used to detect any effects of sample date and treatment on ECM colonization rates across the whole data set.

Simple linear regression was used to determine whether the distance of seedlings from the edges of the gaps was correlated with mycorrhizal colonization.

ECM diversity and species richness

Simpson's and Shannon's diversity indices for the ECM morphotypes for each group of birch trees in Duchesnay and Rivière à Pierre were calculated (Shannon and Weaver 1949; Simpson 1949). When calculating the morphotype diversity

and richness, each morphotype was considered as a single taxon.

Results

Light regimes

At Rivière à Pierre, the light ranged from 26.4 to 89.1% PPDF in the nine 1000-m^2 gaps, and from 0.8 to 18.4% PPDF in the surrounding areas. At Duschenay, the light levels for the trees in the small gaps were significantly (p = 0.002) lower (0.03–8.35% PPDF) than those from the large gaps (0.02–18.04% PPDF). The considerable overlap in the amount of light present in the gaps versus uncut areas is a result of the many resprouting trees present in the gaps.

Mycorrhizal colonization

The fine roots of 192 of 198 maples sampled from Rivière à Pierre were mycorrhizal. A steady increase in total VAM colonization and colonization by arbuscules was seen throughout the season (Figs. 1a and 1b), whereas coils peaked in August (Fig. 1c). No relationships between VAM colonization and the distance of each seedling from the gap edge were detected (r^2 = 0.016, p > 0.05). Analyses of the whole data set show that seasonal effects on total colonization, arbuscule colonization, and coil colonization were all highly significant (p < 0.001). The overall analysis also showed that total colonization, colonization by arbuscules, and colonization by coils was higher in the gaps than in the uncut areas (p = 0.002, 0.004, and 0.007, respectively); differences for individual sample dates are shown in Figs. 1a– 1c, respectively. For all comparisons, the treatment × date term was not significant (p > 0.05). Vesicle levels increased slightly as the season progressed; however, the numbers remained low throughout the sampling season, and no statistically significant effects of date or gaps were detected (Fig. 1d).

At Duchesnay, there were no differences in colonization between the maple seedlings collected from the 9- and 3- year-old gaps; therefore, the data for these two groups were pooled. Total VAM colonization and colonization by arbuscules and coils varied significantly with date (p < 0.0001); total colonization and colonization by arbuscules tended to peak towards the end of the season, while coils tended to be more abundant during June (Figs. 2a–2c). Total colonization and colonization by arbuscules varied by gap size (p = 0.028 and p = 0.037, respectively), both tending to be higher in the gaps (Figs. 2a and 2b). As at Rivière à Pierre, vesicles were present in low numbers throughout the season in both large and small gaps (Fig. 2d), and no statistically significant effects of season or gap size were detected.

At Rivière à Pierre, ECM colonization levels of the yellow birch roots were very high throughout the season (Fig. 3a). No significant effect of gap size or sample time on ECM colonization levels was found, although colonization levels were always slightly higher in seedlings from the uncut forest than those from the gaps (Fig. 3a). The saplings in the 9- and 3-year-old gaps at Duchesnay showed a significant effect of sampling date (p < 0.001) and gap size (p < 0.001) on ECM colonization rates, while the date × gap size interaction was not significant (p = 0.963). The colonization rates were higher on the saplings collected from the large gaps as

opposed to the small gaps, and the colonization rates were low in the spring and increased as the season progressed (Fig. 3b).

At both sites, the distribution of the different ectomycorrhizal morphotypes was similar for all treatments (Fig. 4). Morphotype M1 was dominant at all sampling dates, under all treatments, and at both sites; all other morphotypes were present at relatively low frequencies (Fig. 4). The diversity and richness of ECM morphotypes did not differ between treatments at either site (Table 1); however, the morphotype diversity was higher at Duchesnay, where morphotype M1 was less dominant (Fig. 4).

A total of 16 different mycorrhizal morphotypes were found on the birch rootlets collected from both sites. In Duchesnay, 14 different morphotypes were found and 15 were found at Rivière à Pierre (Table 1). Thirteen morphotypes were common to both sites. Three of the 14 morphotypes found on the Duchesnay birch seedlings were present on only 11 of 100 (11%) seedlings collected. Four of the 15 morphotypes found on the seedlings collected at Rivière à Pierre were present on 19 of the 198 (9.6%) seedlings. The 11 remaining morphotypes were present at both sites and were more commonly found. Figure 4 gives colonization rates only for the 11 most common morphotypes from each site.

Discussion

The high levels of mycorrhizal colonization in both yellow birch and sugar maple seedlings suggest that creation of the gaps did not disrupt the mycorrhizal community or reduce inoculum potential for either the ECM or VAM system. Interestingly, the ECM colonization rates of yellow birch seedlings collected from the 1000-m^2 gaps and the uncut forest at Rivière à Pierre did not differ, whereas saplings from the larger gaps at Duchesnay had higher colonization rates than those from the smaller gaps. That higher levels of VAM colonization of sugar maple were seen in the 1000-m^2 gaps at Rivière à Pierre and in the large gaps in Duchesnay may suggest that the mycorrhizal system of sugar maple may respond more rapidly than the ECM system of yellow birch to changes resulting from selective cuts.

The high ECM colonization of yellow birch at Rivière à Pierre (86–99%) in all treatments suggests that the already established mycelial network was able to colonize the seedlings. Not only the lack of soil disturbance, but also the prompt regeneration (within 6 months) of yellow birch and other ectomycorrhizal species such as beech, may have helped to sustain the indigenous fungi. The stumps of mature beech and yellow birch trees that were left intact after the cuts in the previous fall could also have been important in maintaining the natural inoculum, as the excised roots of both species can remain viable for at least 9 months under field conditions (Ferrier and Alexander 1985). In our study, yellow birch sprouted from the stumps in the following spring, indicating a sufficient carbohydrate reserve to support the growth of lateral branches. As root carbohydrate reserves show seasonal trends, with peaks in spring and fall (Ferrier and Alexander 1985), cutting in the fall may have aided the survival of the stumps and their associated mycorrhizal fungi. The maintenance of native ECM

Fig. 1. VAM colonization of the sugar maples from Rivière à Pierre: (*a*) total VAM colonization; (*b*) colonization by arbuscules; (*c*) colonization by coils; (*d*) colonization by vesicles. Bars are the means, and error bars are the 95% confidence intervals. Solid bars are uncut areas; open bars are gaps.
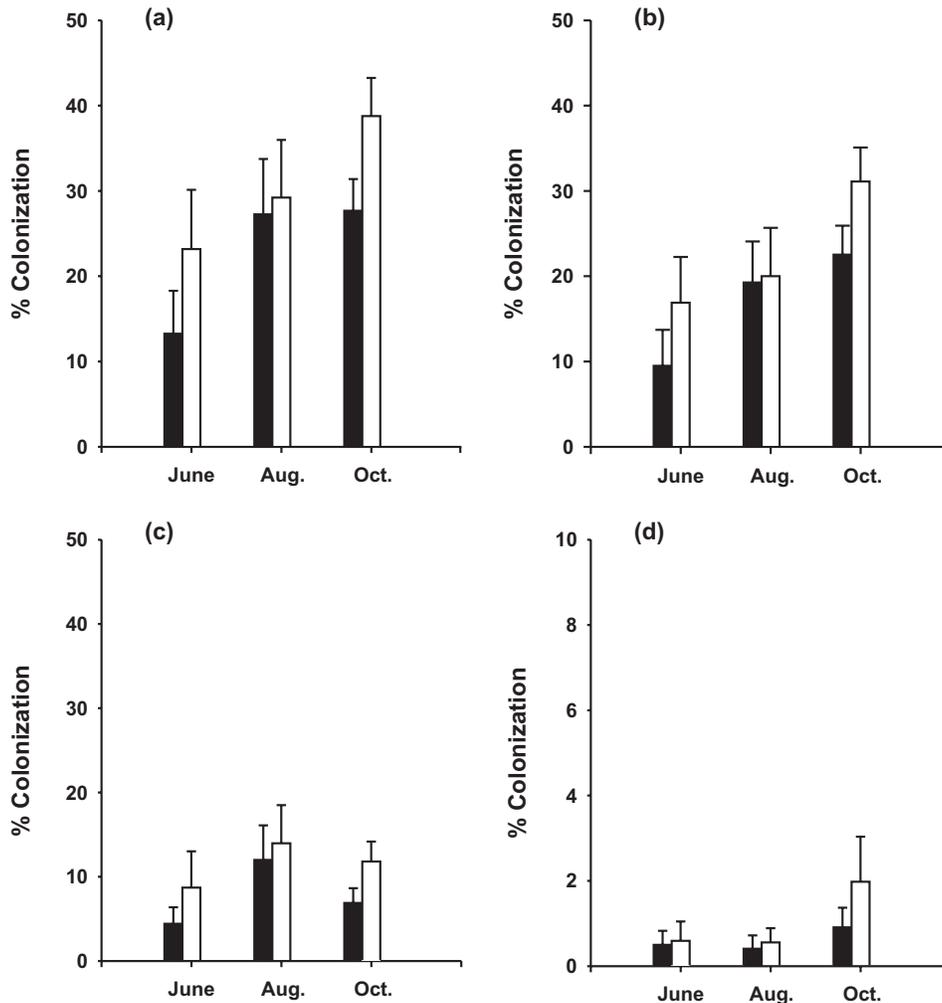

inoculum may be very important as nursery seedlings colonized with easily culturable ECM fungi, when planted into cleared areas, are often outperformed by those colonized by native ECM fungi (Zhou et al. 1997). Visser et al. (1998) have also shown high ECM colonization in aspen, which can form root sprouts, in both clear-cut and uncut areas and have attributed this to the maintenance of the ECM inoculum, because of low forest soil disturbance and the persistence of the mycorrhizal roots on stumps.

The ECM morphotypes on the yellow birch seedlings in the gaps were similar to those from the uncut areas (Fig. 4) and from the roots of mature trees in the uncut forest (J. Coburn, unpublished data). Visser et al. (1998) also found no differences in the ECM morphotypes on aspen from the cut and uncut forest. Kranabetter and Wylie (1998), Durall et al. (1999), and Hagermann et al. (1999), however, all report decreases in ECM fungal richness on the roots of conifers from cut areas compared with those from uncut areas. Kranabetter and Wylie (1998) found reductions in fungal richness on 4-year-old naturally regenerating western hemlock seedlings growing in ~2000- to 4400-m² gaps. Durall et al. (1999) found reductions in fungal richness in gaps of

900–5000 m² on lodgepole pine and western hemlock seedlings collected 2 years after outplanting. Hagermann et al. (1999) found no differences in the ECM diversity and numbers of active root tips of subalpine fir and Engelmann spruce seedlings in gaps versus uncut areas in a subalpine forest in British Columbia in the first season, but significant reductions were present in the second and third growing seasons following the cuts. Kranabetter and Wylie (1998) and Hagermann et al. (1999) also state that the diversity of ECM fungi in the cuts was significantly reduced with distance from the forest edge. As these conifers do not form sprouts from roots or stumps, after a cut the roots are depleted of their carbon stores and gradually die. Thus, there may be a fundamental difference between the impact of a cut on the mycorrhizae of nonsprouting species, which include most conifers, as opposed to species that sprout, such as birch and aspen. The newly formed aboveground parts of sprouting species may provide energy that helps maintain the ECM fungal community on the roots.

The diversity of ECM morphotypes was slightly higher in the older saplings collected from Duchesnay than in the 2-year-old seedlings from Rivière à Pierre, even though the

Fig. 2. VAM colonization of the sugar maples from Duchesnay: (*a*) total VAM colonization; (*b*) colonization by arbuscules; (*c*) colonization by coils; (*d*) colonization by vesicles. Bars are the means, and error bars are the 95% confidence intervals. Solid bars are small gaps; open bars are large gaps.
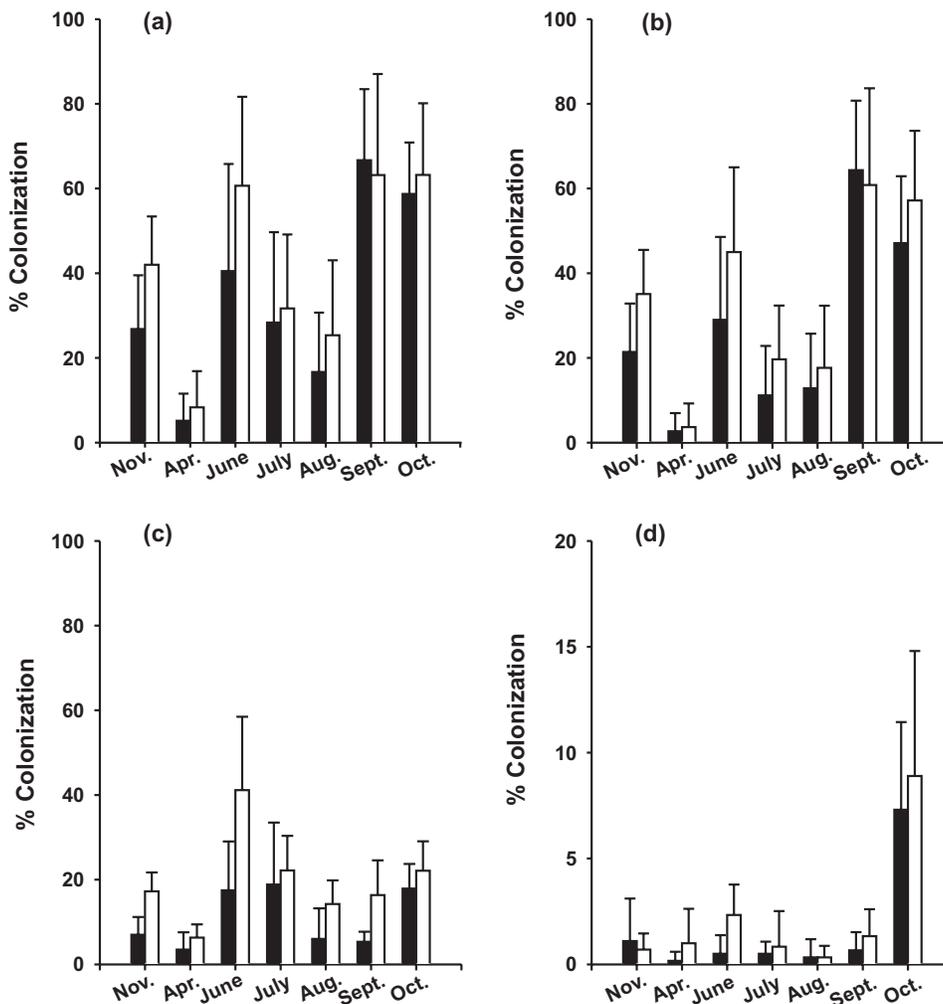

species richness was slightly lower. This was due to the higher dominance of the orange-smooth morphotype (M1) at Rivière à Pierre. Dahlberg and Stenström (1991) and Danielson and Pruden (1989) have also shown that diversity tends to be lower on younger seedlings.

In contrast to the ECM, VAM colonization rates in the sugar maples collected from both sites increased significantly in the gaps. The maintenance of a healthy VAM community in the gaps may also be a result of the relatively minor level of soil disturbance coupled with quick regeneration and the presence of many VAM hosts. Sugar maple, striped maple, red maple, and pin cherry were all present in the gaps the following spring, along with many herbaceous VAM plants. Arbuscule levels were significantly higher in the maples collected from large gaps at Duchesnay and in 1000-m² gaps at Rivière à Pierre than those from the small gaps or uncut areas. High arbuscule numbers coupled with low vesicle numbers is usually a sign of a healthy mycorrhizal association. Many studies have reported a decrease in arbuscule levels and an increase in vesicle numbers in sugar maples that are in a state of decline (Cooke et al. 1992; Costanzo 1999; Duckmanton and Widden 1994).

Cooke et al. (1992) and Kliromomos (1995) observed levels of colonization by vesicles from 15 to over 30% coupled with extremely low levels of colonization by arbuscules in sugar maples growing in acidic soils. During this study, colonization by vesicles at both Duchesnay and Rivière à Pierre never rose above 10%, while colonization by arbuscules peaked at 60% in Duchesnay and 23% in Rivière à Pierre.

Information on VAM fungal colonization in maples from natural environments is scarce. Brundrett and Kendrick (1988) showed that in a forest in southwestern Ontario, colonization peaked in September in both seedling and mature sugar maples. Klironomos (1995) examined mature maples from forests in southern Ontario and found that total colonization levels varied from 30 to 70%, while arbuscules peaked at ~17%. Arbuscule levels in our study were higher than those reported by Klironomos (1995) but similar to those reported by Costanzo (1999), who found that 2-year-old sugar maple seedlings growing in pots containing forest soil had mean colonization rates by arbuscules of ~60% for the month of September whereas vesicle levels were about 5%. At the end of the sampling season (September and October), for the present study, colonization levels in

Fig. 3. ECM colonization of the yellow birch: (*a*) Rivière à Pierre, solid bars are uncut areas, and open bars are gaps; (*b*) Duchesnay, open bars are small gaps, and solid bars are large gaps. Bars are the means, and error bars are the 95% confidence intervals.
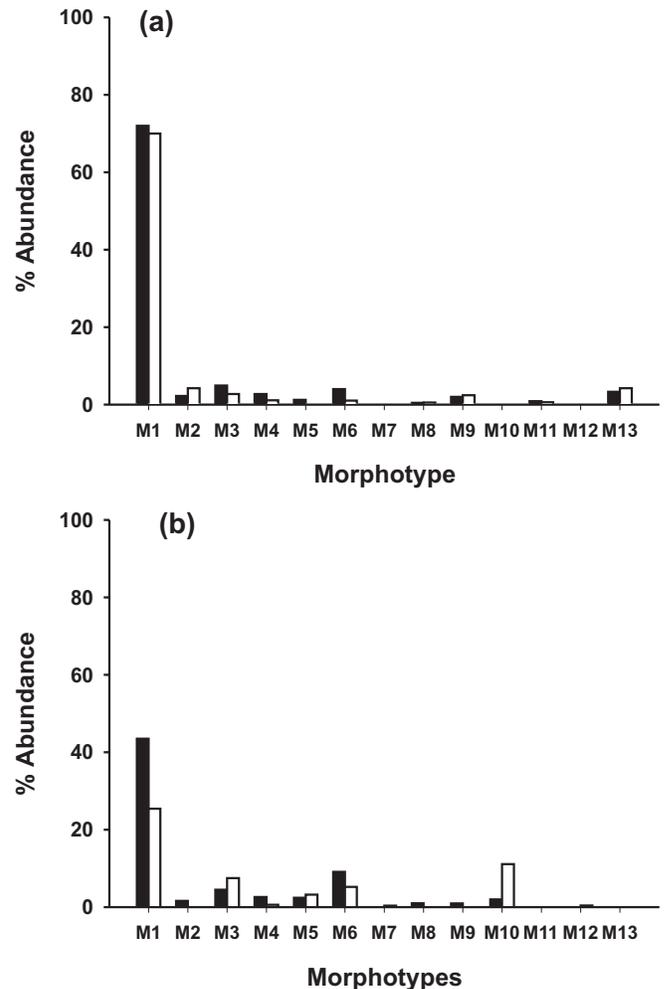

Fig. 4. Ectomycorrhizal morphotype abundance for (*a*) Rivière à Pierre, solid bars are uncut areas and open bars are gaps; (*b*) Duchesnay, open bars are small gaps and solid bars are large gaps.
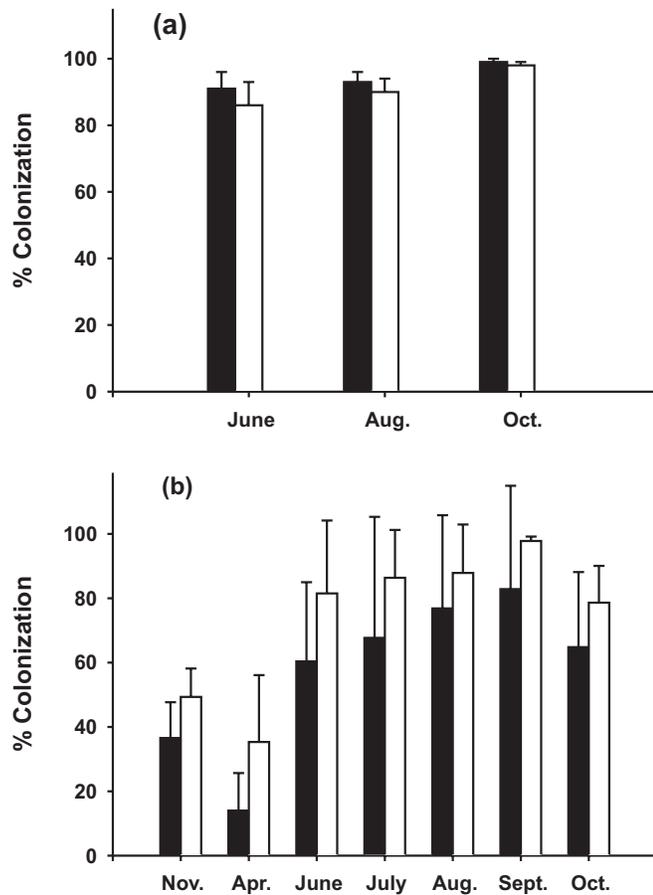
Duchesnay were much higher than those observed at Rivière à Pierre. VAM colonization levels can be affected by many environmental conditions (Cooke et al. 1992; Duke et al. 1994; Klironomos 1995); thus, differences may be attributed to possible environmental differences between the two sites as well as to differences in the ages of the seedlings.

At both sites, VAM colonization was higher where light levels were higher. It is well known that VAM colonization increases with the amount of light received by the host plant (Bethlenfalvay and Pacovsky 1983; Furlan and Fortin 1977; Gerdemann 1968; Hayman 1974; Nemec 1987; Pearson et al. 1991; Son and Smith 1988). This effect is generally attributed to the photosynthetic activity of the plant and increased carbon stores. The increase in numbers of arbuscules in plots with higher light that we observed has also been observed in other studies (Franken and Gnädinger 1994; Hayman 1974; Pearson et al. 1991). Since arbuscules are the site of nutrient transfer, seedlings in the gaps may benefit more from the VAM fungi by increased nutrient uptake than those in uncut areas.

In summary, the selective cuts, performed in winter with minimal soil disturbance, did not appear to disrupt the mycorrhizal systems of either yellow birch or sugar maple.

Table 1. Diversity and richness of morphotypes of the ECM fungi on the yellow birch from Rivière à Pierre and Duchesnay.

	Rivière à Pierre		Duchesnay	
	Uncut area	Gap	Small gap	Large gap
Richness	15	15	14	14
Simpson's diversity	1.6	1.7	2.6	2.4
Shannon's diversity	1.1	1.1	1.0	1.0

However, the VAM of sugar maple appeared to respond more rapidly to the cuts, producing more arbuscules in the cut areas, possibly enabling the young trees to take maximum advantage of available energy. Also of some interest is the fact that the community of ECM morphotypes on yellow birch seedlings did not appear to change in time, as the young seedlings at Rivière à Pierre had a similar ECM community to the 5- to 10-year-old seedlings at Duchesnay, and preliminary data (J. Coburn, unpublished) indicate that both were similar to the communities of ECM on mature trees at

both sites. These results agree with data indicating that seedlings growing within a mature forest acquire the late-stage fungi present on the mature trees (Fleming 1983) rather than supporting the succession of species seen in plantations (Dighton and Mason 1985). However, to clearly understand the ectomycorrhizal community, it is necessary to combine both morphological and genetic methods to relate morphotypes to genotypes and, ultimately, to the actual species of fungi fruiting and present on the roots of both seedling and mature trees. This more detailed analysis of the ectomycorrhizal community on yellow birch from these two site will be the subject of a future communication.

Acknowledgments

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