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Sugar maple and yellow birch regeneration in response to canopy opening, liming and vegetation control in a temperate deciduous forest of Quebec

Dodick Gasser[a,*], Christian Messier[a], Marilou Beaudet[a], Martin J. Lechowicz[b]

[a] Centre d'étude de la forêt (CEF), Département des Sciences Biologiques, Université du Québec à Montréal, C.P. 8888, Succursale Centre-ville, Montréal, QC H3C 3P8, Canada
[b] Centre d'étude de la forêt (CEF), Department of Biology, McGill University, 1205 Docteur Penfield, Montréal, QC H3A 1B1, Canada

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ABSTRACT

We examined how the density, growth and survival of sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton) regeneration are influenced by gap size, soil nutrient availability and understory vegetation. We used a factorial combination of (1) three gap sizes (small: <100 m^2; medium: 100–300 m^2; large: ~1000 m^2); (2) presence/absence of liming (92% $CaCO_3$ at 500 kg ha^{-1}, 1st year post-harvest); and (3) presence/absence of vegetation control (weeding twice a year; 1st to 3rd year post-harvest). We monitored height increment and survival of 1500 seedlings and saplings of both species from the 3rd to the 6th year post-harvest, and assessed density 6 years post-harvest. Both species exhibited a complex set of density, growth and survival responses across the combination of treatments. Compared to sugar maple, yellow birch had an overall lower density, greater growth, and similar survival rate; the two species attained maximum values in different gap size for density, and similar gap size for growth and survival. Liming had very little or no effect on the species. The growth of yellow birch was slightly but significantly greater when understory vegetation was controlled, particularly in medium and large gaps. These results suggest that a variety of canopy gap sizes can provide the right combination of understory conditions for regenerating these two functionally different tree species.

1. Introduction

Variation in the size of canopy gaps is thought to favor the coexistence of species with contrasting shade tolerance (Bormann and Likens, 1979; Pickett and White, 1985; Busing and White, 1997; Valladares and Niinemets, 2008). For example, the coexistence of sugar maple (*Acer saccharum* Marsh.) and yellow birch (*Betula alleghaniensis* Britton) has been explained by species-specific differences in growth and survival across a range of gap sizes (Forcier, 1975). Sugar maple is considered a shade tolerant species (Canham, 1988), yellow birch mid-tolerant (Erdmann, 1990). There is, however, no clear evidence for a simple relationship between gap size and the distribution, abundance and relative performance of the two species (McClure and Lee, 1993; Sipe and Bazzaz, 1994; Raymond et al., 2006). This may reflect our poor understanding of interactions among factors such as light, soil nutrient availability, and understory vegetation that are associated with variation in gap size and that can affect regeneration success (Bazzaz and Wayne, 1994; Coll et al., 2003; Bartemucci et al., 2006; Raymond et al., 2006).

Variation in soil fertility can influence sugar maple and yellow birch regeneration (McClure and Lee, 1993; Finzi and Canham, 2000; Bigelow and Canham, 2002; Gilbert and Lechowicz, 2004), particularly in medium and large gaps (Canham et al., 1996; Ricard et al., 2003). Sugar maple requires relatively high soil fertility, while yellow birch requirements are less clearly defined (Cogliastro et al., 1997; Anderson et al., 2001). Although sugar maple abundance is associated with high Ca availability (Long et al., 1998; Arii and Lechowicz, 2002; Bigelow and Canham, 2002), the effects of variation in soil exchangeable Ca and associated variation in soil pH on the growth and survival of these two species are inconclusive (Kobe et al., 1995, 2002; Long et al., 1998; Bigelow and Canham, 2002). Understory vegetation may also interfere with sugar maple and yellow birch regeneration, and the effect may vary with gap size. Light availability can be much diminished by a dense layer of understory vegetation in gaps (Royo and Carson, 2006). Both shade intolerant species, such as pin cherry (*Prunus pensylvanica* L.) and raspberry (*Rubus idaeus* L.), and shade tolerant species, such as beech (*Fagus grandifolia* Ehrh.) and striped maple (*Acer pensylvanicum* L.), interfere with regeneration of other temperate deciduous species (Heitzman and Nyland, 1994; Ricard and Messier, 1996; Beaudet et al., 2004; Nyland et al., 2006; Royo and Carson, 2006). Although sugar maple has a high survival under shaded condi-

* Corresponding author at: Consortium en Foresterie Gaspésie-Les-Îles, 190, rue Armand-Lelièvre, 2e étage, Local 114, New Richmond, QC G0C 2B0, Canada. Tel.: +1 418 392 2667; fax: +1 418 392 5440.
E-mail address: dodick.gasser@mieuxconnaitrelaforet.ca (D. Gasser).

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tions (Kobe et al., 2002) and a generally abundant seedling bank (Marks and Gardescu, 1998), it does not grow as fast as yellow birch under higher light conditions (Berkowitz et al., 1995; Kobe et al., 1995). This might increase the probability of sugar maple being overtopped by surrounding vegetation when growing in large openings. On the other hand, yellow birch has a faster growth rate, especially in high light, which may enable it to outgrow competing vegetation in gaps, but its poor survival rate under low light is believed to make it a weak competitor in shade (Logan, 1965; Erdmann, 1990).

This study seeks to advance our understanding of the dependence of sugar maple and yellow birch regeneration on interactions in this complex of environmental factors. We assess sugar maple and yellow birch regeneration in an experiment in which we manipulate not only gap size but also soil nutrient availability and the abundance of adjacent understory vegetation. We anticipated that small gaps would favor sugar maple due to its high survival in shade, whereas larger gaps would favor the growth and survival of yellow birch. We also expected that liming and vegetation control would be more beneficial for sugar maple than yellow birch. We test these expectations and discuss the silvicultural relevance of the effects of gap size, liming and vegetation control for regenerating these two commercially valuable species.

2. Materials and methods

2.1. Study site

We conducted the experiment in the Portneuf wildlife reserve near Rivière-à-Pierre, Quebec, Canada (47°04′N, 72°15′W), which lies in the sugar maple-yellow birch bioclimatic domain (Robitaille and Saucier, 1998). The study site covers 60 ha between 320 and 430 m a.s.l on the north-facing side of a hill with slope varying from 9 to 16%. Mean annual temperature is 2.5 °C, mean annual precipitation varies from 900 to 1400 mm, of which 25–30% fall as snow, and the growing season lasts from 160 to 180 days (Robitaille and Saucier, 1998). The surface deposit is an undifferentiated till approximately 1 m deep overlaying granitic bedrock. Soils are well to moderately well drained and range from brunisols to podzols. The humus is a moder or mor according to the location. Stoniness is low (<13%) and the mean root depth was 26 cm. Average soil pH is 4.2. The overstory is dominated by sugar maple, yellow birch and beech (54, 23 and 11% of pre-harvest basal area [BA], respectively), with red maple (*Acer rubrum* L.), red spruce (*Picea rubens* Sarg.), balsam fir (*Abies balsamea* (L.) Mill.) and paper birch (*Betula papyrifera* Marsh.) also present. The pre-harvest BA, stand density and mean DBH were 23.3 $m^2\,ha^{-1}$, 710 stems ha^{-1} (DBH > 10 cm) and 20.4 cm, respectively. The mean height of co-dominant and dominant trees (as defined in MRN, 2002) ranged from 17 to 22 m. The stand structure is uneven-aged with some evidence of old partial cuttings. The forest was not damaged by the 1998 ice-storm. The understory vegetation is mainly composed of sugar maple, yellow birch, beech, pin cherry and red maple seedlings and saplings, in addition to striped maple, mountain maple (*Acer spicatum* Lam.), hobblebush (*Viburnum alnifolium* L.), yew (*Taxus canadensis* Marsh.) and elderberry (*Sambucus* L.) in the shrub layer. The most representative species in the herbaceous layer are starflower (*Trientalis borealis* Raf.), American red raspberry (*R. idaeus* L.), Canada mayflower (*Maianthemum canadense* Desf.), mountain wood sorrel (*Oxalis Montana* Raf.), spinulose woodfern (*Dryopteris carthusiana* (Vill.) H.P. Fuchs), New York fern (*Thelypteris noveboracensis* (L.) Nieuwl.), long beech fern (*Phegopteris connectilis* (Michx.) Watt), shining clubmoss (*Huperzia lucidula* (Michx.) Trevis.), and big red-stem moss (*Pleurozium schreberii* Mitt.).

2.2. Experimental design

Harvesting took place in November–December 1996, creating 50 large patches (~1000 m^2) located along north-south transects and separated by approximately 50 m from border to border. An improvement cut was performed between these large patches with a removal rate of approximately 20% of the basal area, creating smaller gaps of various sizes (from a few squares meters up to 300 m^2). Trees were harvested whatever their species and diameter, but defective stems were removed in priority and most branches left on site and spread around as to not impede regeneration. Except for the traffic of machinery, understory vegetation was not intentionally destroyed, and no specific scarification was performed. Three one-hectare areas along the slope gradient were uncut as a control.

The experimental design is a three-way factorial: gap size (three levels described subsequently), liming (two levels: presence/absence) and vegetation control (two levels: presence/absence). Gaps of three sizes were selected: small (<100 m^2, corresponding to a gap diameter/tree height (D/H) ratio <0.6), medium (100–300 m^2, i.e., D/H of 0.6–1) and large gaps (~1000 m^2, i.e., D/H of 1.8). Each of the 12 resulting combinations of treatments was replicated 12 times for a total of 144 plots. Small, medium and large gaps (*n* = 36, 23, and 12, respectively) were randomly selected across the study area. Combinations of liming and vegetation control were applied in 7 m × 7 m plots within gap size. Forty-eight 49 m^2 monitoring plots were set up for each gap size (48 × 3 = 144 plots). The number of plots established in each gap varied depending on gap size: only one plot was installed in each of 24 small gaps as well as in one of the medium gaps; two plots were installed in each of 12 small and 19 medium gaps; three plots were installed in each of three medium gaps; and four plots in each of the 12 large gaps. Five 7 m × 7 m plots were set up in the uncut part of the study site, were not limed, nor weeded, and thus serve as control.

The four combined treatments of liming and vegetation control were randomly assigned to the 49 m^2 plots within each gap size. In early July 1997 (first post-harvest growing season) we applied both lime powder (92% $CaCO_3$ and 0.76% $MgCO_3$) at 500 kg ha^{-1} and KCL at 25 kg ha^{-1} in each treated plot as well as in a 0.5 m wide buffer strip around the plots. To bring acid forest soil near neutrality requires on the order of several tons per hectare (Long et al., 1997; Burke and Raynal, 1998; Houle et al., 2002). We sought only to increase the availability of soil exchangeable calcium and potassium, which can offset several nutritional deficiencies of sugar maple (Camiré et al., 1997; Côté, 1998); calcium and potassium deficiencies had been demonstrated in a nearby sugar maple stand (Moore and Ouimet, 2006; Ouimet et al., 2008).

The vegetation control treatment involved hand-weeding in the plots and their buffer of all species of forbs, shrubs and trees of less than 2 cm in dbh except sugar maple and yellow birch seedlings and saplings of seed origin; we note that sugar maple and yellow birch stump sprouts were eliminated. Ferns, graminoïds and club-mosses were left in place unless they covered more than 50% of the ground. All cut vegetation was removed from the plot. This procedure was repeated in early June and again in early August for the first three growing seasons after gap creation. This treatment was meant to emulate the kind of vegetation control done by managers in these forests.

In autumn 1999, nearly 1500 seedlings of sugar maple and 1500 seedlings of yellow birch were tagged for individual monitoring, i.e., roughly 10 seedlings of each species per plot. For yellow birch, most of the selected seedlings had established after the cut. For sugar maple, which was abundant as advance regeneration, a maximum height of 50 cm was defined as a selection criterion.