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On the relationship between saplings and ingrowth in northern hardwood stands

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ABSTRACT

We used long-term data collected from 22 study sites in northern hardwood stands comprised of sugar maple (*Acer saccharum* Marsh.), yellow birch (*Betula alleghaniensis* Britt.), and American beech (*Fagus grandifolia* Ehrh.) to establish relationships between sapling abundance and tree ingrowth. After 10 years, postharvest sapling density in the 6 cm diameter class (5.1–7.0 cm) showed linear relationships with ingrowth. Proportion of variation explained (r^2) varied from 36% to 83% depending upon tree species and silvicultural treatment (partial cutting vs. uncut control). After 20 years, linear relationships were also established (r^2 = 24–65%) between ingrowth and sapling density in the 2 cm diameter class (1.1–3.0 cm). From a wide pool of variables related to stand species composition, climate, physiography, and soil nutrients, postharvest sapling density was most strongly correlated to merchantable tree density (r = 0.43–0.75). Sugar maple sapling density was also positively correlated with base saturation and calcium saturation of the B horizon (r = 0.56 and 0.58). Over a 30-year period, the increase in American beech sapling basal area was substantial compared to mitigated increases found in sugar maple and yellow birch depending upon treatment. Our results provide useful information on integration of sapling data into forest management.

1. Introduction

In northeastern North America, hardwood forests provide a myriad of ecosystem services, including habitat for vertebrate wildlife species, recreational opportunities, watershed protection, and wood products (Leak et al., 2014). Deciduous angiosperms predominate in these forests, from shade-tolerant species like sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.) to mid-tolerant species like yellow birch (*Betula alleghaniensis* Britt.). Although each species has commercial value, sugar maple and yellow birch are generally more desirable than beech. Northern hardwood forests are often uneven-aged and characterized by small-scale disturbance that allows saplings (diameter at breast height (DBH) >1.0 and ⩽9.0 cm) to grow to merchantable size (>9.0 cm DBH). Historically, single-tree selection and group selection have been the main silvicultural treatments recommended to regenerate uneven-aged northern hardwood stands (Nyland, 1996; Leak et al., 2014). Although long-term responses of these partial cutting treatments on stand yield and diameter growth of individual trees are well understood (e.g. Bédard et al., 2012; Swift et al., 2012; Leak et al., 2014), there is less information on recruitment of saplings into merchantable size (Donoso et al., 2000). How many saplings are needed to obtain at least one recruit? How much time is required for a sapling to reach merchantable size? Does sapling size or species matter? Is there a minimum threshold of sapling abundance required to ensure the stand's long-term sustainability? What potential factors help explain sapling abundance, including silvicultural practices? These are important questions that have received less attention in the scientific literature compared to growth of merchantable trees and stand yield. Given that ingrowth is essential to ensure the long-term sustainability of a stand, there is a need to increase our knowledge to better manage northern hardwood forests.

Recent literature on long-term sapling dynamics in northern hardwood forests has documented an increase in beech over sugar maple over the past 40–50 years. Examples are found in uncut stands of several Canadian provinces and American States (Bedison et al., 2007; Duchesne and Ouimet, 2009; Gravel et al., 2011; Sullivan et al., 2013). Soil cation depletion appears to be an important limiting factor of sugar maple regeneration survival in forests affected by acid deposition (e.g., Moore et al., 2012; Marlow and Peart, 2014). Other studies, however, suggest that the increase in beech over maple cannot be explained solely by

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the soil cation depletion hypothesis (Gravel et al., 2010, 2011). Additional contributing factors may include preferential browsing by increasing white-tailed deer (*Odocoileus virginianus* Zimm.) populations on maple (Long et al., 2007; Matonis et al., 2011), and increased competitiveness of beech due to asexual reproduction (Jones and Raynal, 1986; Beaudet and Messier, 2008; Wagner et al., 2010). Beech bark disease (BBD) is another important issue affecting regeneration dynamics in northern hardwood forests across northeastern North America (Griffin et al., 2003; Morin et al., 2007). This disease is caused by feeding of the beech scale insect (*Cryptococcus fagisuga* Lind.) and subsequent infestation by fungi (e.g., *Nectria galligena* Bres. in Strass) that kills a large proportion of mature beech. Impacts of BBD on regeneration dynamics are still uncertain (Evans et al., 2005). Thus, we aim to build on this body of knowledge by investigating the influence of silvicultural practices and potential integration of sapling data into forest management. Studies that deal with this aspect in the literature are rare (Nolet et al., 2008; Bannon et al., 2015).

Our study uses up to 30 years of empirical data gathered from 22 study sites to investigate relationships between saplings and tree ingrowth (>9.0 cm DBH) in managed and unmanaged northern hardwood forests. Our data also offers an opportunity to examine changes in sapling abundance after harvest for three of the most common species: sugar maple, American beech, and yellow birch. Hence, for each species the objectives of this study were to: (1) establish relationships between sapling abundance, i.e., density or basal area (BA), and ingrowth after 10 and 20 years with or without partial cutting; (2) determine factors that help explain sapling abundance, such as overstory composition, climate, and soil properties; (3) quantify the change in sapling abundance over 30 years.

2. Materials and methods

2.1. Study area

Data used in this article were pooled from 22 study sites across the province of Québec, Canada (Fig. 1). Sites were located in the northern temperate vegetation zone (Saucier et al., 1998), and covered three bioclimatic domains across a latitudinal gradient (45.5–47.9°N): sugar maple – American basswood (*Tilia americana* L.), sugar maple – yellow birch, and balsam fir (*Abies balsamea* (L.) Mill.) – yellow birch. A longitudinal gradient (67.1–78.6°W) was also present, with a few sites extended in the western and eastern regions of Québec (Fig. 1). Depending upon treatment, mean postharvest density of merchantable trees ranged from 393 to 510 stems ha^{-1} and mean stand BA ranged from 18.8 to 26.2 m^2 ha^{-1} (Table 1). Species composition was generally dominated by sugar maple (>50%), followed by yellow birch and American beech (Table 1). Mean preharvest sapling density was 809 stems ha^{-1}, with sugar maple accounting for 61%, followed by American beech (34%), and yellow birch (4%). Postharvest sapling density was just below 560 stems ha^{-1}, harvesting operations reduced sapling density by 30% (Table 2).

2.2. Experimental design and silvicultural treatments

Partial cutting trials ($n = 65$) were carried out in each study site between 1983 and 1999. Twelve trials were established at the Duchesnay research forest (DUC, 46°57′N, 71°40′W), 24 trials were established at the Mousseau research forest (SVE, 46°35′N, 74°58′W), and the remaining trials established across the province (Fig. 1). Initially, each trial was composed of paired experimental units (EUs). One EU was harvested (2 ha) and the other was left as an untreated control (1 ha). EUs were split into 0.25 ha sections (50 × 50 m) to facilitate inventory. Given logistical and financial constraints, however, only one or two 0.25 ha sections were re-measured over time for saplings. Hence, within each EU we combined data from all sections to avoid artificially increasing our sample size. In general, trials were re-measured every ten years. The actual number of EUs used varied according to each objective based on the presence of saplings of each species and diameter class, and silvicultural treatment. Single-tree selection cutting (∼30% merchantable BA removal) was most frequently used. Selection cuts were aimed at reducing mortality losses, improving stand quality, and maintaining an uneven-aged structure on a rotation that ranged from 15 to 25 years.

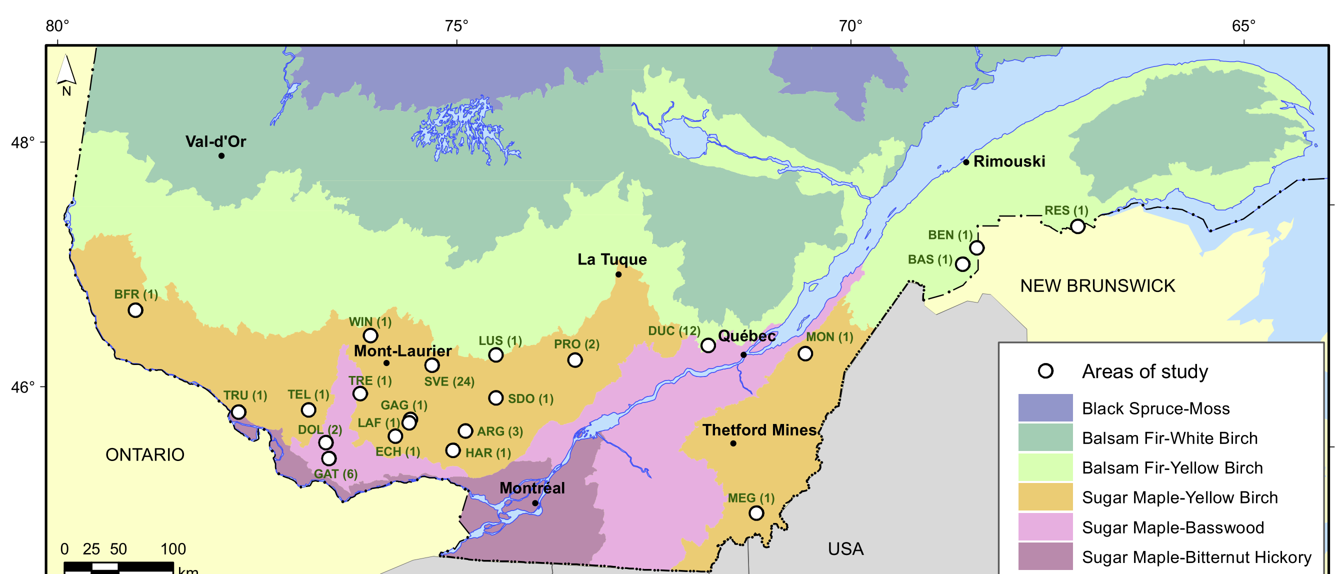

Fig. 1. Location of the 22 study sites in Québec, Canada. Sites are located within three bioclimatic domains (Saucier et al., 1998) along a latitudinal gradient: sugar maple – basswood, sugar maple – yellow birch, and balsam fir – yellow birch. Full names of study sites are: ARG, Argenteuil; BAS, Basley; BEN, Benedicte; BFR, Bois Franc; DOL, Lac Doley; DUC, Duchesnay; ECH, Lac Echo; GAG, Lac Gagnon; GAT, Gatineau; HAR, Harrington; LAF, Lac Lafontaine; LUS, Lusignan; MEG, Lac Mégantic; MON, Montmagny; PRO, Lac Provision; RES, Restigouche; SDO, Saint-Donat; SVE, Sainte-Véronique; TEL, Lac Telfer; TRE, Lac Trente-et-un-Miles; TRU, Lac-à-la-Truite; WIN, Lac Windigo. The number of cutting trials is shown in parentheses.