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# Management legacy in the understory of North American mixed boreal regenerating stands

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ABSTRACT

In the global context of planted forest expansion, the ability of artificially regenerated forests to stand-in for natural forests has become a central question for forest managers. Although few studies have examined their conservation potential, extensive planted forests cover a significant portion of North-American mixed boreal forests. We study the composition, functional assemblage, and vertical structure of understory communities in even-aged, mid-rotation, planted and naturally regenerated mixed boreal stands typical of extensive management (Québec, Canada). Our results show that more than 20 years after harvest, species composition and functional assemblage still differ between stand types while understory structure does not. Planted stands exhibit a higher prevalence of traits and species typically associated with younger stands. Sensitive species such as *Oxalis acetosella* ssp. *montana* and *Monotropa uniflora* occurred less often in planted stands while the reverse was true for a portion of species with the potential to form a recalcitrant layer. This suggests that the understory of planted sites may require more time before reaching compositional and functional attributes comparable to those of naturally regenerated stands. This delayed maturation has implications for forest management, particularly under increased management intensity scenarios.



## 1. Introduction

As net global forest areas continue to shrink (FAO and JRC, 2012) and forests management intensifies, the rapid spread of planted forests prompts questions as to their ability to stand-in for the natural forests they replace. Planted forests have attracted significant attention due to their high environmental impact (reviewed in Moore and Allen, 1999), high timber yield and the debate around the conservation potential of these forests (Carnus et al., 2006; Brockerhoff et al., 2008; Paquette and Messier, 2009), particularly in intensively managed tropical (Zou et al., 2014) and European (Coote et al., 2012; Onaindia et al., 2013) systems. The main concerns associated with these man-made ecosystems are related to their contrasting capacity to maintain natural ecological processes, which is primarily determined by their degree of naturalness (composed of exotic or native species) and the intensity of management performed, both at the establishment phase and throughout the rotation (Carle and Holmgren, 2003).

Traditionally managed much more extensively and reforested using native species, North-American mixed boreal planted forests contrast with those in other parts of the world. After initial mechanical and/or chemical control of current vegetation, these artificially regenerated stands are typically managed so as to emulate naturally regenerated stands, under relatively long rotations and with little intervention between harvests (Park and Wilson, 2007). Despite representing a significant portion of Canada and North-Eastern U.S. (Maine Forest Service, 2010; Natural Ressources Canada, 2011), their conservation potential has received relatively little attention.

In a comparison between planted and naturally regenerated stands in eastern Canada, Ramovs and Roberts (2005) found that understory communities of artificially regenerated stands of this biome could remain dissimilar from naturally regenerated forests for at least 60 years. Convergence (i.e. increasing compositional, functional and structural similarity with time) of artificially and naturally regenerated stands can depend on many factors, including land-use history (Gachet et al., 2007), landscape matrix (Honnay et al., 2001), biological legacy (Swanson et al., 2010) as well as the proximity of propagule sources, such as remnant

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mature stands (Vellend, 2003). Forest management strategies involving a suite of post-harvest silvicultural treatments are conducive to contrasted differences between naturally regenerated and planted stands (Newmaster et al., 2007). In planted stands, the very short interval (<2 yrs) between clear-cutting and site preparation results in a compounded double-disturbance event (Pidgen and Mallik, 2013). Predictably, disparity between the two types of stands, and therefore time to convergence, might increase directionally with management intensity (Brockerhoff et al., 2008). In North American mixed boreal forests, the primary uncertainty surrounding planted forest conservation potential is therefore the effect of higher management intensity at the establishment stage in comparison with naturally regenerated stands.

An increase in management intensity during rotation could also become a conservation issue. Mid-rotation commercial thinning of even aged stands is increasingly used to raise productivity while enhancing structural diversity (Schütz, 2002; Juodvalkis et al., 2005; Davis and Puettmann, 2009). In mixed boreal stands, this practice has recently been suggested as a restoration alternative for some regions grappling with an unbalanced age structure (too many young, even-aged stands) (Gagné et al., 2012; Lavoie et al., 2013). Such practices, despite having direct positive effects on tree growth, can release other forest components and indirectly limit seedling development. A typical example is the competition which can occur between some understory plants and young trees when a disturbance releases a previously limiting resource (e.g. light or nutrient availability). In many parts of the world, increases in management intensity and frequency have been shown to disrupt understory dynamics, an impact which can be exacerbated in the competition-driven communities found in very low and very high productivity environment, where it can increase susceptibility to invasion (Alpert et al., 2000; Kohv et al., 2013). This can lead to the development of a recalcitrant understory layer (*sensu* Royo and Carson, 2006) that stunts or delays tree growth (Jobidon, 1995; Royo and Carson, 2006; Young and Peffer, 2010). Although these highly competitive layers are well documented, studies have focused mainly on "after the fact" observations of full-blown recalcitrant layer, while very few have documented the mechanisms at play upstream of release. There is a clear need for an improved mechanistic understanding of the processes involved in understory development in mixed boreal planted forests in order to inform management and silvicultural practices. In these extensively managed planted forests, does a higher level of disturbance at the stand establishment phase favor competitor release?

Many approaches exist to measure the impact of disturbances on understory vegetation, but all of them aim to characterize one or all three of the principal aspects of biodiversity: composition, function and structure (Noss, 1990; Carnus et al., 2006). The traditional taxonomic approach is useful in detecting some fine-scale patterns, notably the occurrence of rare species. The trait approach reflects the successive filtering processes operating at different scales, affecting local species assemblages and giving rise to a layered, non-random assembly of plant communities in any one location (Diaz and Cabido, 2001). By looking for emerging syndromes of co-occurring traits (*sensu* McIntyre et al., 1999), this method lets us arrive at the mechanisms behind the assemblage, while maintaining greater comparability with other study systems worldwide (Aubin et al., 2007; Lavorel et al., 2007). Finally, structural analysis makes possible a more refined appraisal of successional dynamics operating within the community (Bartemucci et al., 2006). These three approaches (taxonomic, functional and structural) are complementary and allow us to assess the various dimensions of plant community response to anthropogenic disturbance.

In this study, our primary objective was to compare the understory composition, functional assemblage and structure between artificially and naturally regenerated forests. Although the study area is currently managed extensively, increases in management intensity mid-rotation (commercial thinning) are planned for stands of both origins (Lavoie et al., 2013). Here we ask whether understory development follows similar patterns in naturally and artificially regenerated stands, and focus both on the conservation potential of planted forests and on their likelihood of developing a recalcitrant understory layer following future management activities. Because site productivity is likely to affect community response to anthropogenic disturbances (Kohv et al., 2013), the secondary objective of our study is to compare sites belonging to two contiguous classes of ecosystem productivity for stands of both origins, and to assess whether these two factors (site origin and productivity class) can combine to increase the potential for developing a recalcitrant layer.

## 2. Materials and methods

### *2.1. Study area and study sites*

The study was performed in the high Appalachian plateau of the Lower Saint-Lawrence region of Quebec, Canada (Robitaille and Saucier, 1998). This area is characterized by gently rolling hills averaging 365 m in elevation. Surficial deposits consist of glacial till of variable depth and sit atop sedimentary bedrock. Mean annual temperature is 2.1 °C and precipitations average 992 mm yearly, a third of which falls as snow (Environnement Canada, 2009); the growing season typically lasts between 150 and 160 days (Robitaille and Saucier, 1998). Our sites were located in an area of mixed-wood forests totaling approx. 2 Mha; conifer species in this area include balsam fir (*Abies balsamea* (L.) Miller), white spruce (*Picea glauca* (Moench) Voss) and eastern white cedar (*Thuja occidentalis* L.) while deciduous species are mainly represented by yellow birch (*Betula alleghaniensis* Britton) and white birch (*Betula papyrifera* Marshall) (Grondin et al., 1998). Edaphic conditions vary in a continuum depending on humus type, pH, drainage and slope, with yellow birch or white birch dominating as companion species to fir in sites recognized as more or less fertile, respectively (Blouin and Berger, 2002). These forests have been primarily subjected to even-aged management practices, with rotational clear-cuts on a 60–70 year cycle. White spruce is the species primarily involved in reforestation, with planted forests representing 11% of forests in the region (Observatoire de la Foresterie du Bas-Saint-Laurent, 2007).

Twenty mixed stands clear cut approximately 25 years ago were selected according to: stand origin (artificial or natural regeneration) and stand productivity (yellow birch/fir stand type; paper birch/fir stand type, hereafter called high and low productivity). Stand age and origin were determined from provincial forest inventory maps and subsequently field validated using *in situ* tree cores (see Table 1 and Section 2.3 for more details). These even aged stands are embedded in a forest matrix and correspond to mid-rotation stage. A single 0.1 ha plot was installed within each of the twenty selected stands (5 per combination of stand origin and productivity).

Artificially regenerated stands were planted with indigenous white spruce. A proportion of naturally occurring balsam fir was also found in these stands. Naturally regenerated stands were dominated by balsam fir (Table 1). The two stand productivity classes represent closely related ecological types and were chosen according to Blouin and Berger (2002) classification. All selected plots had mesic soil conditions (see Table 1 for environmental variables description). At most planted sites, site preparation involved trenching. This was followed by herbicide application as well as