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Does partial harvesting promote old-growth attributes of boreal mixedwood trembling aspen (*Populus tremuloides* Michx.) stands?

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ABSTRACT

In the current context of forest ecosystem management, partial harvesting has been proposed as a silvicultural tool to augment forest variability on managed landscapes and to accelerate the development of structural and compositional attributes of old-growth/late successional stands. The aims of this paper were to (1) identify and characterize, based on the literature, the structural attributes of old-growth aspen-dominated stands in the North American boreal mixedwood forest, and (2) examine the short-term potential of partial harvesting in aspen-dominated stands to accelerate stand development toward these old-growth characteristics. Two stand types – pure aspen (93% aspen basal area) and mixed aspen (81% aspen basal area) – were monitored over a 12-year post-treatment period. The scientific literature suggests that compared to pure, even-aged premature or mature stands, old-growth aspen stands have lower merchantable stem densities and basal area, more large aspen stems, higher stem size variability, more than one cohort of trees, greater percentage area occupied by gaps, higher expanded gap area, and more and larger snags and downed wood. In addition, old-growth aspen mixedwoods characteristically have more shade-tolerant conifers in understory and overstory layers than younger, mature stands. Results of this study indicate that light thinning from below (33% basal area removal) applied in pure aspen stands successfully retained most of the structural attributes of mature aspen stands, but did not generally "accelerate succession" toward old-growth traits in the 12-year time interval since treatment. A dispersed free thinning (45% basal area removal in all merchantable size classes) applied in mixed aspen stands showed its potential to "accelerate succession" by creating canopy gaps similar to old-growth aspen stands and by promoting recruitment of both tolerant and intolerant tree species. Two high intensity partial harvesting treatments, a thinning from above of 61% basal area in pure aspen stands and 400 m^2 gap cuts (54% basal area removal) in mixed aspen stands may set back stand development by disproportionally favoring recruitment and growth of intolerant hardwood species.

1. Introduction

The concept of forest ecosystem management (FEM) has taken hold in many parts of the World (Gustafsson et al., 2012; Lindenmayer et al., 2012), including Canada (Burton et al., 2003; Gauthier et al., 2009). Forest ecosystem management recognizes the importance of mitigating the differences between natural (that is, unmanaged and of natural disturbance-origin) and managed forest landscapes, and as such, silvicultural practices are underpinned by an understanding of how natural disturbance and ecosystem processes affect stand dynamics (Grumbine, 1994; Christensen et al., 1996). The natural disturbance emulation approach of FEM aims, in part, to mitigate the undesirable impacts of generalized application of clear-cutting and its variants on biodiversity (Fedrowitz et al., 2014) and ecosystem processes (Likens et al., 1978; Keenan and Kimmins, 1993), thus favoring long-term sustainability of ecosystem goods and services (Christensen et al., 1996).

Partial harvesting has been identified as a key silvicultural tool in the implementation of FEM in the boreal forest (Lieffers et al., 1996; Bose et al., 2014c). Partial harvesting is a generic term, which refers to a whole range of harvesting treatments from clear-cutting with dispersed retention in which a few merchantable stems are left on site, to single-tree selection systems. It is assumed that partial harvesting can (1) contribute to maintaining ecosystem functions within their historical range of variability by retaining greater residual structure in harvested forests (Drever et al.,

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2006; Franklin et al., 2007; Gauthier et al., 2009), and (2) potentially accelerate stand development toward an old-growth stage – or accelerate the acquisition of compositional and structural characteristics associated with the old-growth stage. This may occur, in part, by creating growing space of variable sizes for new cohorts of trees (Franklin et al., 2002; Harvey et al., 2002). Old-growth stands have been recognized as functionally and structurally diverse relative to young, intensively managed stands (Spies and Franklin, 1988; Mosseler et al., 2003; Franklin and Van Pelt, 2004) and stands with high structural variability are considered more likely to provide a variety of wildlife habitats (Fischer et al., 2006) and, at least theoretically, to increase ecosystem resilience to environmental stresses (Drever et al., 2006).

In Canada, boreal mixedwoods generally occur on relatively productive sites and have long been recognized as being among the most structurally complex stand types in the Canadian boreal forest (De Grandpré and Bergeron, 1997; Chen and Popadiouk, 2002; Haeussler et al., 2007). In boreal mixedwoods, shade-intolerant hardwoods, mostly trembling aspen (*Populus tremuloides* Michx.) and white birch (*Betula papyrifera* Marsh), and shade-tolerant conifers coexist in different proportions depending on time since the last stand replacing fire, climatic factors and interactions between a range of abiotic and biotic factors (Bergeron et al., 2014; Nlungu-Kweta et al., 2014). Locally, trembling aspen can regenerate profusely by suckering (vegetative reproduction from roots), a process which is generally favored by severe disturbances (Perala, 1974; Frey et al., 2003; Brais et al., 2004), and boreal aspen stands have been traditionally managed under even-aged (clear-cut) silvicultural systems (MacDonald, 1995; Bergeron et al., 2002). However, studies conducted in boreal mixedwood forests have shown that, in the absence of fire, aspen may regenerate successfully in gaps, leading to older, uneven-aged stands with distinct aspen cohorts (Bergeron, 2000; Cumming et al., 2000; LeBlanc, 2014).

Regional studies have provided insights into the range of attributes that define old-growth aspen stands or mixed aspen stands in the boreal forest (Lee et al., 1997; Bergeron, 2000; LeBlanc, 2014). However, a more comprehensive review of the attributes of old-growth boreal trembling aspen stands is required to assess the effectiveness of partial harvesting of even-aged aspen stands to promote the development of these attributes. The potential of partial harvesting to promote old-growth characteristics has been tested for northern hardwood forests in the United States (Singer and Lorimer, 1997; Goodburn and Lorimer, 1998; Keeton, 2006), and Canada (Angers et al., 2005), and in other parts of the world (Barbati et al., 2012; Motta et al., 2014), but not for aspen-dominated boreal mixedwoods of North America. Studies conducted in boreal mixedwoods have shown that partial harvesting can create multi-layer canopies by favoring recruitment of intolerant hardwood regeneration and establishment of conifer regeneration (Prévost and Pothier, 2003; Man et al., 2008a; Bose et al., 2014b). However, Haeussler et al. (2007) found that while partial harvesting treatments in aspen-dominated mixedwoods may retain attributes of un-harvested stands, in the short term, they do not necessarily hasten the development of older stand attributes. Moreover, by destroying well-decomposed logs (Brais et al., 2004), partial harvesting can also cause a loss of structural variability and species diversity (Haeussler et al., 2007).

The objectives of this study are to (i) identify and quantify structural attributes that characterize old-growth aspen-dominated mixedwoods of the North American boreal forest and (ii) examine whether specific partial harvesting treatments applied 12 years previously in pure and mixed aspen stands promote structural attributes of old-growth stands in the mid-term. Using percentage of basal area removal as a proxy for harvesting intensity, we tested the following hypotheses: (1) low intensity, diffuse partial harvesting creates few large gaps and retains most of the structural attributes of even-aged stands (O'Hara, 1998; Haeussler et al., 2007); (2) high-intensity partial harvesting treatments applied in either a regular (diffuse) or a gap pattern create a higher percentage of canopy gaps and wide tree spacing. This in turn will produce greater variability in tree size classes through recruitment and growth of a second cohort of aspen (Ball and Walker, 1997; McCarthy, 2001; O'Hara, 2001) and promote the growth of saplings of late successional species, when present (Brais et al., 2013; Prévost and DeBlois, 2014). However, high-intensity partial harvesting will reduce the density of large trees, the density and basal area of standing snags and the volume of downed logs relative to untreated control stands (Angers et al., 2005; Keeton, 2006).

2. Methods

The first objective was addressed through a search of the scientific literature conducted in July–August 2014 to collect studies reporting on structural attributes of old-growth aspen-dominated boreal mixedwoods of North America. Pertinent scientific publications were identified using online search engines Google Scholar and Web of Science and combinations of the following keywords: "boreal", "aspen forest", "aspen stand", "aspen mixedwoods", "old-growth", "forest succession", "coarse woody debris", "snags", "gaps". We retained publications that met the following criteria: (1) sites were located within the boreal biome of North America, (2) stands reported on originated from wild fire and were naturally regenerated with trembling aspen as the dominant early successional species, (3) age of stands or time since stand-replacing fire were known. Among these publications, we further selected for those that (1) compared structural attributes between young-mature aspen, old-growth aspen and late-successional forests, or (2) presented data on stand structural attributes such as canopy, understory vegetation, gaps or deadwood (snags and downed logs) or (3) described changes in these attributes through natural succession. If a number of publications reported data from common sites, only the most informative publication was retained. We finally retained 19 studies conducted in the Canadian provinces of Alberta (e.g., Lee et al., 1997, 2000), Saskatchewan (e.g., Hobson and Bayne, 2000), Manitoba (e.g., Ball and Walker, 1997; LeBlanc, 2014), Ontario (e.g., Basham, 1958; Hill et al., 2005) and Québec (e.g., Kneeshaw and Bergeron, 1998; Bergeron, 2000) as well as in Minnesota, USA (e.g., Frelich and Reich, 1995) (Table 1). Most studies were published in peer-reviewed journals and provided qualitative or quantitative information on structural attributes of old-growth aspen forests.

For our purposes, old-growth was defined as stands between 100 and 200 years of age (LeBlanc, 2014), corresponding to the period following the onset of mortality of the initial post-fire aspen cohort and during which understory stems are recruited into the canopy (Kneeshaw and Gauthier, 2003). The upper limit (200 years) corresponds conceptually to the moment when aspen stems no longer constitute a major portion of stand basal area (Bergeron, 2000). This stage associated with old-growth aspen stands has also been described as an intermediary successional stage in boreal mixedwoods (Bergeron and Harper, 2009).

2.1. Study sites

The second objective was addressed using empirical data. This empirical part was conducted in the Lake Duparquet Research and Teaching Forest (LDRTF) in the Abitibi region of northwestern Quebec, 45 km northwest of the city of Rouyn-Noranda (48°26′N–48°32′N, 79°16′W–79°29′W). The region is characterized by the