Available online at www.sciencedirect.com
ScienceDirect
Forest Ecology and Management 255 (2008) 2916–2927
Forest Ecology and Management
www.elsevier.com/locate/foreco

Influence of fire intensity on structure and composition of jack pine stands in the boreal forest of Quebec: Live trees, understory vegetation and dead wood dynamics

Evgeniya Smirnova *, Yves Bergeron, Suzanne Brais

Chaire en Aménagement Forestier Durable, Université du Québec en Abitibi-Témiscamingue, 445 Boulevard de l'Université, Rouyn-Noranda, QC, Canada J9X 5E4

Received 16 April 2007; received in revised form 30 January 2008; accepted 31 January 2008

Abstract

North American jack pine (*Pinus banksiana* Lamb.) stands are generally characterized by an even-aged structure resulting from high intensity fires (HIF). However, non-lethal fires of moderate intensity (MIF), which leave behind surviving trees, have also been reported. The objectives of this study were two-fold: (1) assess the concurrent dynamics of live trees, understory vegetation and different types of coarse woody debris (CWD) during succession after HIF; and (2) document how MIF affects stand structure component dynamics compared to HIF. Stands affected by both HIF and MIF were selected. Tree characteristics and age structure, understory biomass, and CWD volume were assessed. Our results suggest that the structural succession of jack pine stands following HIF comprises three stages: young stands (<48 years), premature and mature stands (58–100 years) and old stands (>118 years). Canopy openness and jack pine density significantly decreased with time since HIF, while black spruce density and CWD volume significantly increased. The highest structural diversity was measured in the premature and mature stands. Compared to HIF, MIF increased mean jack pine basal area, decreased average stand density, delayed the replacement of jack pine by black spruce replacement in the canopy, decreased CWD volume, and significantly increased bryophytes mass. MIF increased the diversity of live trees and generally decreased CWD structural diversity. The study confirms the diversity of natural disturbance magnitude and successional processes thereby initiated. Thereafter, it appeared to be relevant for adjustment of disturbance emulating forest-management systems.

Keywords: Boreal forest; Jack pine; Fire intensity; Stand structure; Black spruce; Coarse woody debris; Structural diversity

1. Introduction

Fire intensity is defined as the energy produced by a fire event over an area during a period of time. Residual structures within a burned area can be used as an index of fire intensity for some extent (Schimmel and Granström, 1996; Turner et al., 1998). North American jack pine stands are generally characterized by an even-aged, post-fire structure created by stand-replacing, high intensity fires (HIF), in which jack pine is generally replaced by black spruce approximately 150 years after the stand-initiating fire (Bergeron and Brisson, 1990; Bergeron et al., 2004; Gauthier et al., 1993; Lesieur et al., 2002). Although jack pine stands are generally believed to be prone to HIF, some authors (Desponts and Payette, 1992; Gauthier et al., 1993) have reported the occurrence of non-lethal fires of moderate intensity (MIF), which leave behind surviving trees, initiate a new cohort, and retain legacies from the pre-fire stands.

The structural development of boreal forest stands can be summarized by four stages: (1) stand initiation; (2) stem exclusion with self-thinning; (3) canopy break-up, which sometimes leads to the initiation of a new cohort (although not in fire-dependent jack pine); and (4) old growth, characterized by high structural diversity (Oliver, 1981; Kenkel et al., 1997; Boucher et al., 2006).

Functional traits are considered to be a useful tool to understand plant responses to different disturbance characteristics (Schoennagel et al., 2004). The understory composition of jack pine boreal stands can be divided into four functional groups (De Grandpré et al., 1993): dwarf ericaceous shrubs, herbs, bryophytes, and lichens. Most understory species survive

* Corresponding author. Tel.: +1 819 762 0971/2628; fax: +1 819 797 4727.
E-mail addresses: eugenia.smirnova@uqat.ca (E. Smirnova), yves.bergeron@uqat.ca (Y. Bergeron), suzanne.brais@uqat.ca (S. Brais).

0378-1127/$ – see front matter.
doi:10.1016/j.foreco.2008.01.071

fire via buried rhizomes and re-establish quickly after fire, before canopy closure (Schimmel and Granström, 1996). Secondary succession in the understory layer starts with pioneer species such as lichens and herbs (MacLean and Wein, 1977; Nguyen-Xuan et al., 2000). Ericaceous and bryophyte species dominate after canopy closure (De Grandpré et al., 1993). Understory vegetation in old jack pine stands varies from bryophytes (including *Sphagnum* spp.) to lichens depending on site drainage and stand density (Foster, 1985; Béland and Bergeron, 1996; Fenton and Bergeron, 2006; Lecomte et al., 2006).

In several types of boreal stands, CWD dynamics is characterized by a "U-shaped" temporal pattern (Harmon et al., 1986; Sturtevant et al., 1997; Brais et al., 2005; Harper et al., 2005). The early stage of forest development is characterized by relatively high amounts of CWD generated before the disturbance or as a result of it. During the first years after disturbance, self-thinning process also generates debris but generally of small size (Spies et al., 1988; Hély et al., 2000). Further, debris amount declines with time, with little input from regenerating stages (Sturtevant et al., 1997; Kenkel et al., 1997). CWD input peaks during the transitional stage, when even-aged mature stands senesce and shift to an uneven-aged structure (Sturtevant et al., 1997; Harper et al., 2005).

MIF can alter structural diversity, as well as the timing and amplitude of stand developmental stages (McRae et al., 2001). MIF result in a decrease of self-thinning and subsequent growth release (Rothstein et al., 2004; Weisberg, 2004), the initiation of a new jack pine cohort (Bergeron and Brisson, 1990; Gauthier et al., 1993), and changes in species composition, as MIF kills the seedlings and young individuals of late successional species, such as black spruce and balsam fir (Weisberg, 2004). Furthermore, changes in live tree structure induced by MIF may eventually alter CWD dynamics.

Fire behaviour depends on multiple factors: weather conditions, topography, fuel characteristics such as their amount and moisture content (Nelson, 2001; Sandberg et al., 2007). Fire intensity as measured by scorch height (*sensu* Byram, 1959) does not relate directly to fire severity at the ground level because different processes are involved i.e. different phases of combustion vs. pyrolis (Johnson, 1992).

The following suite of time descriptors should be considered, in order to understand how MIF affects post-fire succession and stand structure components: time since stand-replacing HIF; stand age when MIF occurred; and time since MIF. Time since HIF characterizes pre-MIF structural legacies and their interaction with structural components resulting from MIF. Stand age when MIF occurred determines the probability of tree mortality, abundance of CWD, and pre-MIF understory composition. Time since MIF determines post-MIF stand development.

The diversity of natural disturbance magnitude represents a particular interest for disturbance emulating forest management (McRae et al., 2001). Occurrence of non-stand-replacing fires in jack pine stands permits to emulate them by means of variable tree-retention systems; at present the information of successional process in jack pine stands survived MIF is largely missed.

Although a few authors have already described jack pine stand development after HIF (Gauthier et al., 1993; Béland et al., 2003; Hamel et al., 2004; Lecomte and Bergeron, 2005), there has been no study dedicated to the influence of MIF on jack pine stand structural development. The objectives of this study were: (1) to assess the concurrent dynamics and structural diversity of live trees, CWD and understory vegetation during succession after HIF; and (2) to document how MIF alters the dynamics and diversity of these structural components.

The general hypotheses are: (1) MIF provides a rejuvenating effect on stand structure by delaying stand senescence; (2) MIF increases stand structural diversity compared to HIF.

1.1. Study area

The study area is located in northwestern Quebec (Fig. 1; Table 1), in the southeastern Canadian boreal forest. The climate is continental, characterized by a mean annual temperature of 0.7 °C and 890 mm of precipitation falling mainly as rain (Environment Canada, 2004). While the area is part of the Precambrian Shield, Quaternary surface deposits cover most of the territory and the soils of our study sites have evolved from coarse-textured glaciolacustrine deposits (Brais and Camiré, 1992).

2. Methods

2.1. Stand selection

Eleven post-HIF jack pine stands were selected along a chronosequence (HIF stands). The selected stands varied in size from ca. 10 to 20 ha and showed no trace of forestry practices. Nicolas Lecomte (Lecomte et al., 2006) provided the data for two of the stands (H10 and H11: 149 and 155 years after HIF).

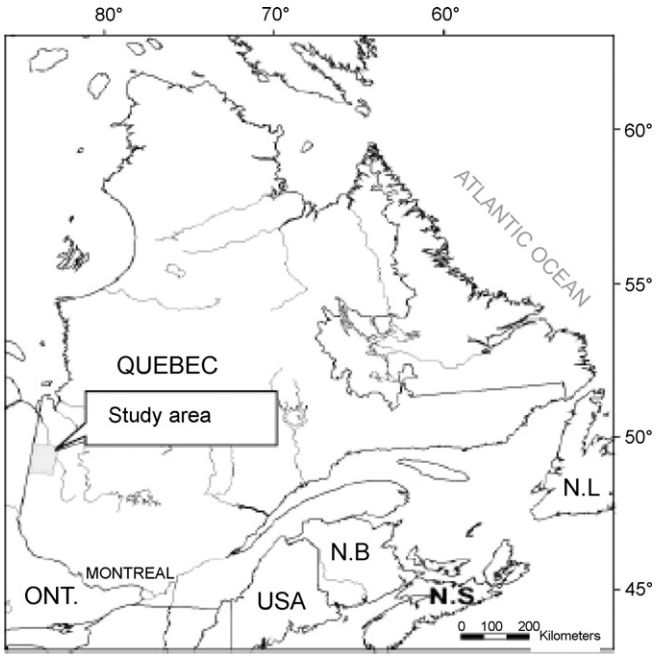

Fig. 1. Location of the study area.