Forest Ecology and Management 289 (2013) 28–37

Contents lists available at SciVerse ScienceDirect

Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Forest structural attributes after windthrow and consequences of salvage logging

Kaysandra Waldron [a,*], Jean-Claude Ruel [a], Sylvie Gauthier [b]

[a] Centre for Forest Research, Université Laval, Québec (Qc), Canada G1V 0A6
[b] Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Québec (Qc), Canada G1V 4C7

ARTICLE INFO

Article history:
Received 13 August 2012
Received in revised form 4 October 2012
Accepted 5 October 2012
Available online 26 November 2012

Keywords:
Windthrow
Salvage logging
Structural attributes
Ecosystem management
Boreal forest

ABSTRACT

In the eastern boreal forest of Quebec (Canada) windthrow is a major natural disturbance, given the long fire cycle interval. Understanding windthrow is essential to ecosystem-based forest management. Dead wood, live trees, and pit-and-mound microtopography are major post-windthrow attributes with known ecological importance. So far, these structural post-windthrow attributes have not been described for this ecosystem. In addition, ecological consequences of salvage logging after windthrow remain unknown, with no specific salvage standard being applied to maintain such attributes and biological legacies. In this study, comparisons were made between salvaged and unsalvaged windthrow to identify which post-windthrow attributes were more greatly affected by harvest operations and to clarify management options. Downed coarse woody debris (downed CWD), snags, live trees, and pits and mounds were characterized. We showed that downed CWD and snags diminished after salvage operations, with a more uniform distribution among decay classes. Pit and mound density was reduced after salvage logging compared to unsalvaged windthrow, with pits being smaller in the salvaged plots. From an ecosystem management perspective, retention patches with dead wood and standing living trees should be kept in salvaged cut-blocks. To minimize salvage operation effects on microtopography, machinery trails should be reduced to a minimum. Also, a certain proportion of windthrow should be exempted from logging operations.

1. Introduction

Ecosystem management, also known as natural disturbance-based management, has become the standard for forest management, not only in many regions of Canada, but also throughout the world (Mitchell and Beese, 2002; Fischer et al., 2006). Understanding natural disturbance is essential for establishing silvicultural treatments that reduce the disparity between natural and managed ecosystems (Gauthier et al., 2009). In the eastern boreal forest of Quebec (Canada) ecosystems can be affected by several episodes of windthrow, both partial and stand-replacing, which make windthrow one of the most important types of natural disturbance in the region (Ruel et al., 2010; Waldron et al., 2012). The higher occurrence of windthrow in the eastern compared to the western part of the boreal forest can be explained by the longer fire cycle in the former (Bouchard et al., 2008). While most studies of natural disturbance in the boreal forest of Quebec have focused on wildfire or insect outbreaks, an increased understanding of windthrow is essential for improving our understanding of forest dynamics, particularly in forests with long forest fire intervals, such the northeastern boreal forest of Canada (Bouchard et al., 2009; Waldron et al., 2012).

Windthrow creates attributes and biological legacies within ecosystems, including dead wood, pit-and-mound microtopography, and seedbed diversity (Beatty and Stone, 1986; Schaetzl et al., 1989; Ulanova, 2000). The ecological importance of snags and woody debris on the ground has been demonstrated repeatedly (Siitonen, 2001; Jonsson et al., 2005). Moreover, organisms that use dead wood are associated with either one or with many specific categories of dead wood and, thus, decay class and size both play a role from an ecological standpoint (Caza, 1993; Siitonen, 2001; Jonsson et al., 2005). Pit-and-mound microtopography refers to the slight surface elevations and depressions that are formed by tree uprooting. Uprooting mixes the soil, increasing nutrient element availability (Beatty and Stone, 1986; Ulanova, 2000). In certain forest ecosystems, these features can cover a relatively high proportion of the forest floor (Ulanova, 2000). This particular form of microtopographic disturbance also exposes or creates a variety of seedbeds, thereby promoting the germination and the growth of different plant species (Peterson and Campbell, 1993; McCarthy, 2001). From the perspective of natural-based management, these post-windthrow attributes should be described.

In many parts of the world, salvage operations are undertaken following episodes of natural disturbance. Effects of salvage log-

* Corresponding author. Tel.: +1 418 656 2131x2890; fax: +1 418 656 5262.
E-mail addresses: kaysandra.waldron.1@ulaval.ca (K. Waldron), jean-claude.ruel@sbf.ulaval.ca (J.-C. Ruel), Sylvie.Gauthier@RNCan.gc.ca (S. Gauthier).

0378-1127/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.foreco.2012.10.006

ging following fire have recently received considerable attention from the scientific community (Nappi et al., 2004, 2011; Greene et al., 2006). Yet, the ecological consequences of salvage logging after windthrow largely remain unknown in Quebec and there is no specific standard by which this technique can be implemented to maintain post-windthrow attributes. This lack of information should induce caution in our current management practices. Indeed, by looking at studies conducted elsewhere in the world on post-windthrow salvage logging (Loeb, 1999; Greenberg, 2001; Lain et al., 2008), we can suppose that key structural attributes as dead wood, pit-and-mound microtopography and live trees would be reduced by salvage logging operations. The comparison between salvaged and unsalvaged windthrow could help highlight those post-windthrow attributes that are more affected by harvest operations (Gauthier et al., 2009) and improve management choices. Therefore, the aims of our study were: (1) to characterize post-windthrow structural attributes and (2) to compare those attributes with a post-windthrow salvage-logged area.

2. Materials and methods

2.1. Study area

The study was conducted in the eastern black spruce-feather moss subdomain of the boreal forest, which lies within the North Shore administrative region of Quebec, Canada (Fig. 1). Black spruce (*Picea mariana* (Mill.) B.S.P.) and balsam fir (*Abies balsamea* (L.) Mill.) are the dominant tree species, but white birch (*Betula papyrifera* Marsh.) and trembling aspen (*Populus tremuloides* Michx.) can also be found. The area is characterized by a fire low occurrence because of its humid and cold climate. Fire cycles on the North Shore range from 270 to over 500 years (Cyr et al., 2007; Bouchard et al., 2008). Mean annual precipitation is about 1300 mm and mean annual temperature ranges between −2.5 °C and 0 °C. The main surface deposit is till, with rock outcrops frequently occurring at the tops of steep slopes (Robitaille and Saucier, 1998).

Given the long fire cycles in the region (Bouchard et al., 2008), windthrow and outbreaks of spruce budworm (*Choristoneura fumiferana* (Clemens)) are the main natural disturbances in this ecosystem, which is affected by gap dynamics (Pham et al., 2004; De Grandpré et al., 2009; Bouchard and Pothier, 2010). Stands with irregular age structure represent a large proportion of black spruce forests of the area (Boucher et al., 2003). In recent years, the region has been severely affected by several windthrow episodes. In 2003, a partial windthrow occurred followed by a major windthrow event in 2006. In total, over 88,000 ha were affected by windthrow (both partial and severe) during this period. A major salvage plan followed the 2006 windthrow. The ensuing salvage operations affected more than 20,000 ha (Ruel et al., 2010).

2.2. Data collection

Salvage logging plans of the main forest products company, Resolute Forest Products, were used to select salvaged sites. Salvaged sites had been harvested in the summer of 2007 or 2008. Not only are downed trees harvested during logging but standing trees are also removed, which helps to compensate for higher logging costs (Roy, 2008) and the reduced wood quality of dead trees (Ruel et al., 2010). Harvesting was conducted with a single-grip harvester and a forwarder. These harvest machines had inflatable tires with chains to increase traction (Jean-François Gauthier, personal communication). Cut-blocks having similar stand characteristics and a wide range of windthrow severities were chosen. High resolution aerial photographs that were provided by the Quebec Ministry of Natural Resources and Wildlife (MRNFQ), together with field estimation, were used to determine windthrow severity of each plot. These severities were distributed over four classes, which were: (1) 0–24%, (2) 25–49%, (3) 50–74%, and (4) 75% or greater stand mortality. Six cut-blocks of approximately 25 ha were sampled. In each cut-block, sampling followed a systematic approach, with a plot (0.04 ha) established every 100 m. Unsalvaged plots were grouped in 12 blocks, based on initial stand and soil characteristics, determined with the forest inventory maps provided by MRNFQ. The number of blocks was higher in unsalvaged treatment as it was not possible to use a systematic approach because of safety and accessibility issues. A relatively wide range of windthrow severities were represented in sampled plots, but, because of safety

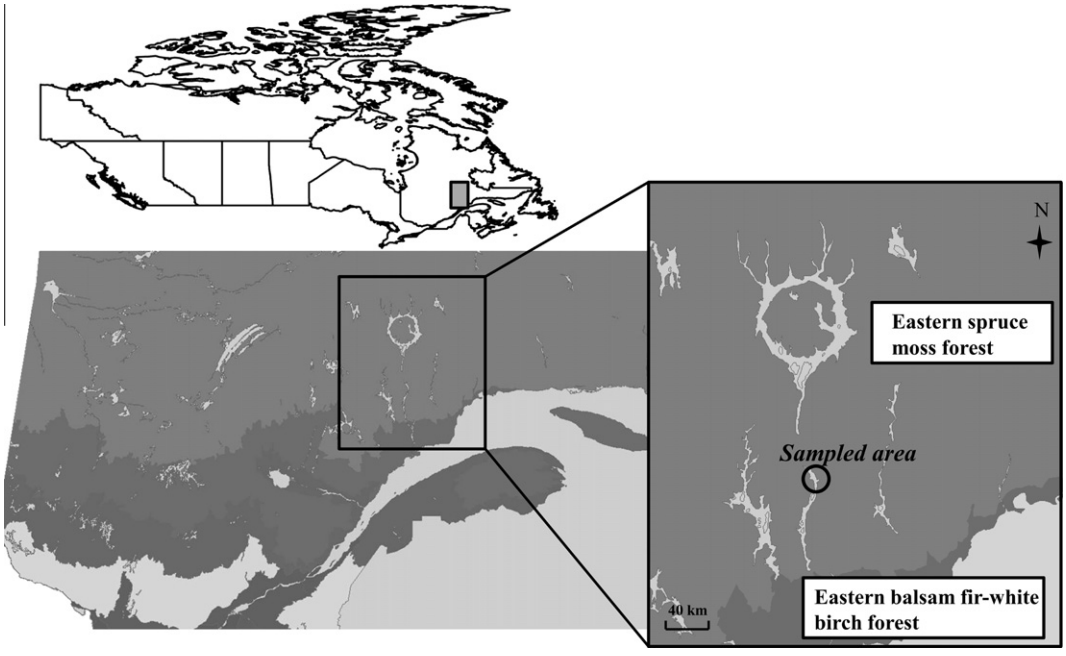

Fig. 1. Study area.