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Salvage logging and forest renewal affect early aspen stand structure after catastrophic wind

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ABSTRACT

Among the major natural disturbances that occur in the North American boreal forest, the effects of catastrophic wind are the least studied due to its infrequent occurrence, often in inaccessible areas, and lack of rapid research response. Most documented studies have been conducted in conifer or mixedwood forests and generally have not considered follow up forest renewal operations such as salvage logging followed by planting and tending. In 2006 after a severe wind disturbance in trembling aspen (*Populus tremuloides* Michx.) forest in northeastern Ontario, we established an operational study to investigate the effects of post-wind disturbance treatments on stand structure (residual live trees, snags, and downed wood) and early forest regeneration. The treatments were blowdown (B), blowdown followed by salvage logging (BS), blowdown followed by salvage logging, windrowing and planting (BSP), BSP followed by aerial spray (tending) with glyphosate 1 year after planting (BSPT), and clearcut (C).

The operational salvage logging removed about 55% of the 60 m^3 ha^{-1} of the snags and 15% of the 390 m^3 ha^{-1} of the coarse downed wood. The relatively low rate of salvage removal increased the abundance (density and stocking) of aspen regeneration and reduced moss cover, but did not affect average height of aspen suckers or the abundance (cover) of other vegetation types. The mechanical operations damaged much of the advanced growth of conifers (mostly black spruce and balsam fir (*Abies balsamea* (L.) Mill.) released by the wind. However, these stems were not sufficiently abundant to contribute significantly to the regenerating forest. Windrowing before planting slightly reduced the amount of area covered by downed wood, while the tending reduced broadleaf regeneration and the abundance of shrubs and increased conifer regeneration and the abundance of grasses. If the management objective is to renew aspen forests lost to catastrophic wind, salvage logging is a viable option to clear the site for regeneration. Forest renewal treatments, including planting and tending, are required when the management objective is conifer regeneration.

1. Introduction

In North American boreal forests, catastrophic wind is one of the stand-replacing natural disturbances (Peterson, 2000; Chen and Popadiouk, 2002; Waldron et al., 2013) that can damage forests over large areas (Nelson and Moser, 2007). Its frequency of occurrence, however, is low (Peterson, 2000; Schulte and Mladenoff, 2005) and varies temporally and spatially (Kramer et al., 2001; Bouchard et al., 2009). As a result, research opportunities are few and therefore understanding of post-wind damage forest dynamics is limited (Cooper-Ellis et al., 1999; Peterson, 2000; Sharik et al., 2010). Research has been conducted mainly in coniferous (Veblen et al., 1989; Kulakowski and Veblen, 2003; D'Amato et al., 2011) and mixedwood (Peterson and Pickett, 1995; Rumbaitis del Rio, 2006) forests. No information is available from trembling aspen (*Populus tremuloides* Michx.) forest, a widely distributed and highly productive forest type in the boreal biome (Rowe, 1972; Perala, 1990). With climate change, the incidence of catastrophic wind may increase as more extreme weather patterns are expected (Meehl et al., 2000; Dale et al., 2001; Schlyter et al., 2006; IPCC, 2007; Olsson, 2009).

As with forest fire and harvesting, catastrophic wind disturbance can dramatically alter forest structure and composition in a short term by depleting the overstory, thereby promoting the development of understory trees and vegetation (Everham and Brokaw, 1996; Peterson, 2000; Moser et al., 2007; Allen et al., 2012). However, destructive wind generates substantial amounts of standing and downed dead wood, both of which provide habitat and structure for maintaining biodiversity (Stevens, 1997), but can impede the recruitment of trees such as trembling aspen as it regenerates mainly through root suckering (Frey et al., 2003).

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Catastrophic wind damage is sudden and therefore differs from insect and disease damage that results in more gradual and selective changes in the overstory. Thus wind damage will likely result in new stands that differ in structure and composition relative to those resulting from fire, harvesting, and insect disturbance (Chen and Popadiouk, 2002; Brassard and Chen, 2006). As small shade tolerant conifers growing under an aspen canopy are more likely to survive catastrophic wind (Kulakowski and Veblen, 2003; Hanson and Lorimer, 2007; Rich et al., 2007; D'Amato et al., 2011), the regenerating aspen forest is expected to have a higher conifer component after wind than after fire or clearcutting, but quantitative data to support this speculation is lacking.

Salvage logging is commonly employed to recover valuable wood and reduce fuel loads and thus fire risk (Lindenmayer et al., 2008; Saint-Germain and Greene, 2009; Fraver et al., 2011). Such logging may be followed by renewal efforts to achieve desired structure and composition in the regenerating forest. Salvage operations change the abundance of standing live and dead trees as well as the amount of downed wood and therefore the forest floor environment. These changes may influence both the abundance and composition of understory vegetation and therefore the regeneration of broadleaf and conifer trees (Lindenmayer and Noss, 2006; Kurulok and Macdonald, 2007; Lain et al., 2008). The logging operation could also directly damage regenerating trees (Peterson and Leach, 2008). To date, several studies have investigated the effects of salvage logging on abundance and composition of understory vegetation and trees after blowdown (Rumbaitis del Rio, 2006; Lain et al., 2008; Peterson and Leach, 2008; D'Amato et al., 2011); these studies however have not considered the effects of subsequent forest renewal operations such as site preparation, planting, and tending.

The objective of this study was to investigate the structure of aspen stands, i.e. the abundance of residual live trees, dead wood (standing and downed), and forest regeneration 5 years after catastrophic wind disturbance followed by salvage logging and forest renewal treatments in comparison with clearcuts. The treatments were blowdown (B), blowdown followed by salvage logging (BS), blowdown followed by salvage logging, windrowing and planting (BSP), BSP followed by aerial spray (tending) with glyphosate the year after planting (BSPT), and nearby clearcut (C). We expected that salvage logging would reduce the abundance of residual live trees, snags, and downed wood, as observed by others (Lindenmayer and Noss, 2006; Lain et al., 2008; D'Amato et al., 2011; Waldron et al., 2013), which would increase tree regeneration and vegetation development relative to that in unsalvaged wind damaged areas (B vs. BS). Second, we hypothesized that windrowing to prepare for planting would reduce the distribution and amount of ground area covered by downed wood and encourage tree recruitment and vegetation development in treated areas relative to salvaged wind damaged areas (BS vs. BSP). Our third hypothesis was that post-plant tending with glyphosate would reduce the abundance of tall vegetation, including broadleaved trees and shrubs, and increase abundance of low vegetation and conifers in salvaged, planted, and tended areas relative to salvaged and planted areas (BSP vs. BSPT).

2. Materials and methods

2.1. Study area

Field plots were located in an area between 48°39′N and 48°41′N and between 83°02′W and 83°05′W about 110 km southwest of Kapuskasing in northeastern Ontario, following a severe wind disturbance that occurred on July 16, 2006. Damaging winds were reported at speeds between 120 and 150 km h^{-1}. Total area of forest that was affected by the damage was about 10,000 ha in an area of 120 km^2. Most of the forest affected by the blowdown was over mature aspen stands, along with some mixedwoods of aspen and black spruce (*Picea mariana* (Mill.) BSP.). The aspen was typically snapped off 2–8 m aboveground, while affected conifers, mostly black spruce, were uprooted. Operational salvage logging was carried out in selected areas in winter 2006–07 and again in winter 2007–08 to recover merchantable aspen, spruce, and jack pine (*Pinus banksiana* Lamb.) and to improve access for forest renewal activities. The blowdown stands that were salvage logged in winter 2006–07 were planted with mixed black spruce (25%) and white spruce (*Picea glauca* (Moench) Voss) (75%) at 1750–1800 stems ha^{-1} in 2007 summer, and sprayed with glyphosate in the following year to ensure survival and growth of planted spruce, practices typically used in conventional conifer plantations in the Canadian boreal mixedwood forest region.

Selected stands originated from a large 1924 wildfire and were dominated by trembling aspen (80% of stand basal area) with variable amounts of black spruce, white birch (*Betula papyrifera* Marsh.), and jack pine prior to blowdown. Selected stands belonged to Ontario's ecosite classification of Aspen-Birch broadleaves on fresh, silty to fine loamy, and moist, silty to fine loamy to clayey sites (Ecological Land Classification Working Group, 2009). Based on the Canadian classification system, soils belong to the Brunisolic order, and based on the World Reference Base for Soil Resources they are Cambisols (Soil Classification Working Group, 1998). Shrub species were predominantly mountain maple (*Acer spicatum* Lam.) and beaked hazel (*Corylus cornuta* Marsh.). Common understory vegetation included dwarf raspberry (*Rubus pubescens* Raf.), wild red current (*Ribes rubrum* L.), twinflower (*Linnaea borealis* L.), bush honeysuckle (*Diervilla lonicera* Mill.), naked miterwort (*Mitella nuda* L.), wild sarsaparilla (*Aralia elata* (Miq.) Seem.), bunchberry (*Cornus canadensis* L.), wild lily-of-the-valley (*Maianthemum canadense* Desf.), and feather mosses (*Hylocomium* spp.).

2.2. Experimental design

The overall study layout was a completely randomized design with five replications (stands) for each of the five blowdown-salvage-renewal treatments: blowdown (Blowdown, B); blowdown followed by salvage logging in 2007–08 winter (Blowdown−Salvage, BS); blowdown followed by salvage logging in winter 2006–07 and windrowing and planting in 2007 with mixed black spruce (25%) and white spruce (75%) at 1750–1800 stems ha^{-1} (Blowdown–Salvage–Planting, BSP); blowdown followed by salvage logging in winter 2006–07, windrowing and planting in 2007 with mixed black spruce and white spruce at 1750–1800 stems ha^{-1}, and chemical tending with aerial spray of glyphosate in 2008 (Blowdown–Salvage–Planting–Tending, BSPT); and nearby clearcuts harvested in the fall of 2005 using full tree harvesting without site preparation and planting (Clearcut, C). Treatment plots ranged from 1 to 2 ha with a minimum 30 m buffer from treatment edge or standing trees/stands.

2.3. Standing and downed wood surveys

In each of 25 experimental stands, live tree ($\geqslant$4 m in height) and standing snag ($\geqslant$0.5 m in height) measurements were conducted in three circular overstory plots of 11.28 m radius, with at least 40 m between plot centres. Data were collected at the time of treatment plot establishment in 2008 for treatments B, C, and BSP, in 2009 for treatment BS, and in 2010 for treatment BSPT. All live trees and standing snags were tallied for species, diameter at breast height (DBH), and height. Snag height was recorded by height class using 2 m increments from 1 (representing heights