Forest Ecology and Management 325 (2014) 118–127

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Salvage logging affects early post-fire tree composition in Canadian boreal forest

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ARTICLE INFO

Article history:
Received 5 February 2014
Received in revised form 2 April 2014
Accepted 3 April 2014
Available online 8 June 2014

Keywords:
Salvage logging
Fire severity
Post-fire composition
Vegetative reproduction species
Aerial seedbank species
Among-site heterogeneity

ABSTRACT

Salvage logging following fire has become increasingly used during the last few decades as a way to mitigate economic losses caused by fire. The removal of burned mature trees including their aerial seedbanks immediately after fire could have impacts on post-fire tree recruitment but specific effects are still unknown. We conducted a study of a fire in the boreal forest of Québec, Canada, to answer the following questions: Does fire severity influence tree compositional changes after fire? Does salvage logging affect these changes by favouring species that can reproduce vegetatively? Does salvage logging reduce among-sites heterogeneity relative to natural post-fire forests? To address these questions, we measured pre- and post-fire tree stocking (2 years after fire) of burned forest of different pre-fire stand composition types both in salvaged and non-salvaged sites, whereas fire severity was measured in the latter only. Species composition was evaluated using a Principal Component Analysis, and mixed models were used to test the effects of canopy fire severity, residual organic layer thickness, stand type and salvage logging on pre- to post-fire composition changes. In non-salvaged sites, fire severity had a significant effect on composition changes, and the effect depended on stand type. Low fire severity favoured species that can reproduce vegetatively such as *Populus tremuloides*, whereas moderate and high fire severity favoured the aerial seedbank species such as *Pinus banksiana* and *Picea mariana*. We found no effect of residual organic layer thickness on post-fire composition changes. Salvage treatment had a significant effect on post-fire composition changes and the effect depended on stand type. Overall, salvage logging tended to favour species relying upon vegetative reproduction more than fire alone, which favoured *P. banksiana*. Although among-site heterogeneity after salvage logging was not smaller than after fire only, salvage alters species composition more than does natural fire alone. Since salvage logging and low severity portions of the burn, which are generally not salvaged, both favour tree species with vegetative reproduction, our results suggest that these species will increase their dominance throughout the landscape if burned forests are systematically salvaged. We suggest strategies that can help to attenuate this divergence from natural post-fire conditions.

1. Introduction

Fire is a major disturbance driving species compositional change in many forest biomes (Heinselman, 1981; Johnson, 1992). For instance, between 1990 and 2008, on average *circa* 5800 km^2 (0.42%) of the Canadian commercial boreal forest was disturbed annually by fire (Gauthier et al., 2014). Salvage logging, introduced as a way to decrease the negative economic impacts of forest fire by recovering timber volume, has become increasingly common during the last 15 years in North America, Europe, and Australia (Greene et al., 2006; Lindenmayer and Ough, 2006; Lindenmayer et al., 2008; Nappi et al., 2011).

In the fire-prone ecosystems of the boreal forest, many tree species are well-adapted to regenerate after burning (Noble and Gitay, 1996; Greene et al., 1999). Some species, such as *Pinus banksiana* Lamb. and *Picea mariana* (Mill.) B.S.P., have multi-year aerial seedbanks that are mostly dispersed after fire (Lamont et al., 1991; St-Pierre et al., 1992; Lavoie and Sirois, 1998), whereas others such as *Populus tremuloides* Michx. have the ability to spread asexually

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http://dx.doi.org/10.1016/j.foreco.2014.04.002

after fire via new stems arising from the cork cambium of the roots (Barnes, 1966; Schier et al., 1985). While post-fire tree composition is often similar to that existing before fire (Greene et al., 2006; Jayen et al., 2006; Johnstone and Chapin, 2006; Ilisson and Chen 2009a,b), many studies report a shift toward species, such as *P. tremuloides*, with a high capacity for asexual reproduction, at the expense of species relying upon aerial seedbanks (Anderson and Romme, 1991; Greene and Johnson, 1999; Ilisson and Chen, 2009a,b; Gärtner et al., 2014).

Fire severity is one of the factors that are known to affect post-fire forest composition (Schimmel and Granström, 1996; Turner et al., 1999; Johnstone and Kasischke, 2005; Johnstone et al., 2010; Hollingsworth et al., 2013). The effect occurs on two levels: (i) on the forest floor, fire severity affects suitable seedbed availability by reducing soil organic layer depth (Johnstone and Chapin, 2006; Greene et al., 2007), and (ii) at the canopy level, it affects both seed availability and sucker production. At one extreme, a very severe fire may kill a significant part of the aerial seedbank via flaming combustion as well as the sucker-producing roots via smoldering combustion (Wang, 2003; Johnstone and Chapin, 2006). At the other extreme, in a very low-severity fire, the temperature may be insufficient to open the serotinous cones protecting the aerial seedbank (Jayen et al., 2006) and the organic layer reduction by smoldering may be insufficient to enhance the germination success of small-seeded plant species (Greene et al., 2007). Wildfires usually create a mosaic of patches with variable fire severity, and the differential responses of tree species to fire severity may therefore result in a markedly heterogeneous post-fire composition (Turner et al., 1994; Chappell and Agee, 1996; Turner et al., 1999; Haire and McGarigal, 2010).

A second severe disturbance event immediately following fire, such as salvage logging, will interact with the regeneration processes and alter post-fire tree recruitment (Greene et al., 2006). However, the impact of salvage logging on ecosystems is still poorly known (Lindenmayer et al., 2008) and few studies have been conducted on its effect on tree regeneration after fire in the boreal forest (but see Fraser et al., 2004; Greene et al., 2006; Donato et al., 2006; D'Amato et al., 2011). Salvage logging affects post-fire forest composition in three ways. First, the removal of burned mature trees including their aerial seedbanks immediately after fire, before the release of most of the seeds, decrease the quantity of available seeds in the field, as suggested by Donato et al. (2006) and Greene et al. (2006, 2013). Secondly, salvage logging is likely to have a direct impact on the site, especially by reducing the thickness of the charred organic material and decreasing shade (as burnt boles are removed). It has been suggested that salvage logging accelerates soil drying due to snag removal (Purdon et al., 2004; Kurulok and Macdonald, 2007), disadvantaging the seedlings of species that are less tolerant to drought. Finally, many studies noted mechanical negative impacts of salvage logging, i.e. saplings or suckers were killed or strongly injured by the machinery (Fraser et al., 2004; Donato et al., 2006; Greene et al., 2006; Fernandez et al., 2008). Salvage logging is mainly applied in moderately to severely burned forests and its application systematically throughout these burned areas could therefore reduce the heterogeneity naturally induced by fire. For example, Purdon et al. (2004) found that understory plant composition after salvage logging was within the range of variability but did not cover all the variability observed in composition after fire alone.

The present study assessed the combined effect of fire and salvage logging on early post-fire composition in a fire that occurred in the boreal mixedwood forest of Quebec. We first assessed the effect of fire severity on post-fire composition. Since salvage logging is only practiced in moderately to severely burned forests, this allowed us to determine variation in post-fire composition in all severities and to take these effects into account in further analysis. We hypothesized that severe fire will favour the recruitment of seedbank conifer species, whereas low severity fire will favour species that can reproduce vegetatively. We also hypothesized that the removal of seeds in burned trees of aerial seedbank species in salvaged sites will drastically change the post-fire composition by favouring species that can reproduce vegetatively. Further, we hypothesized that the compositional change caused by salvage logging, by favouring systematically the same species, will decrease the among-sites heterogeneity relative to the natural post-fire forest created by contrasting fire severities.

2. Methods

2.1. Study area

The study area is located in the boreal zone, in northwestern Quebec, Canada, near the town of Val-Paradis (49°09′N–79°17′W; Fig. 1). Thin soils characterize the area as there are mainly lacustrine soils in the lower areas and tills and sandy fluvio-glacial soils in the higher areas (Tremblay, 1974). The nearest weather station is located 50 km to the south, in La Sarre (48°47′N–79°13′W), 244 m above sea level. Mean January and July temperatures for the normal period 1971–2000 are −18.2 °C and +16.9 °C respectively, with 148 days without frost (Environment Canada, 2013). Annual precipitation amounts to 890 mm, including 246 mm as snowfall (Environment Canada, 2013).

P. mariana and *P. banksiana* are the dominant tree species in the study region. Some mixed stands of *P. tremuloides, Populus balsamifera* L., *Betula papyrifera* Marsh., *Picea glauca* (Moench) Voss, with occasional *Abies balsamea* (L.) Mill., can also be found. Both *P. banksiana* and *P. mariana* have aerial seedbanks and thus can disperse *in situ* from burnt trees. The former abscises the majority of its seeds within a few months whereas the latter releases seeds far more slowly (Splawinski et al., 2014). Thus, *P. mariana* is more negatively affected by early post-fire salvage than is *P. banksiana* because far more its seeds remain in cone-bearing branches in slash piles or at the landing (Saint-Germain and Greene, 2009). While *P. mariana* is also able to reproduce vegetatively by layering, this reproductive mechanism is not useful for immediate post-fire recruitment (Greene et al., 1999). *P. tremuloides* has abundant, reliable sprouting following fire (Schier et al., 1985; St-Pierre et al., 1992; Greene and Johnson, 1999; Ilisson and Chen, 2009a,b), the ability to sprout has been observed in even very young *P. tremuloides* (Burns and Honkala, 1990). It is a masting species that very occasionally produces extremely large crops of very small wind-dispersed seeds in the late spring; as there is no aerial seedbank, the seeds must come from living trees at the fire edge or the within-burn residual stands. The seeds (and thus, the germinants) are so small that they have the most exacting seedbed requirements of any boreal tree species (Greene et al., 2007).

The studied fire burned 12,540 ha on June 9–11, 1997 (Bordeleau, 1998). The fire was characterized as an intermittent crown fire (Hély et al., 2003). The forest soil was still partially frozen at that time. The preceding fires occurred between 1910 and 1930 (Bergeron et al., 2004) implying that the trees at the time of the 1997 fire were 65–85 years old and thus sexually mature and that aspen was able to produce asexual regeneration (Burns and Honkala, 1990).

In the late summer and autumn of 1997, salvage logging was conducted on most of the burned area, only bogs and steep hills were left out.

2.2. Site selection

During the summer of 1997, we selected 36 blocks of approximately 1 ha each in different forest stands where salvage logging