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Young jack pine and high severity fire combine to create potentially expansive areas of understocked forest

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ABSTRACT

Jack pine is a fire adapted species considered to regenerate well after fires of all severities. The Richardson Fire was an extreme megafire event that burned 576,000 ha of jack pine dominated boreal forest in 2011 in northern Alberta, Canada. Initial scouting immediately after the fire identified a great deal of variability in jack pine regeneration seemingly related to fire severity and pre-fire stand composition. We sampled tree regeneration in 56 pure jack pine stands across the range of fire severity and pre-fire stand ages 1 year post-fire. We found that jack pine regeneration density was greater in older stands (>60 years old) compared to younger stands (<30 years old) and in moderate severity burns compared to high severity burns. In young stands with high severity burns, jack pine regeneration averaged only 1164 seedlings per hectare which is well below current stand densities indicating a potentially understocked future forest. At the landscape level, we extrapolated fire severity to the entire fire area using pre and post-fire satellite imagery and found that the area of young jack pine stands which had a high severity burn, and therefore likely low seedling regeneration, was greater than 130,000 ha with most of this area occurring in patches greater than 500 ha in size. Overall, our results suggest that young jack pine may not be as resilient to high severity fires as previously thought and that a large area of burned boreal forest may be at risk of conversion from a closed canopy forest to a more open canopy woodland ecosystem given the predicted changes in fire regime.

1. Introduction

Large fire events burn the vast majority of forest area disturbed by fire each year in the boreal forest with 3% of fires burning 97% of the area (Stocks et al., 2002).These extreme events are also expected to become even more common in the future with a changing climate (de Groot et al., 2012). The general expectation after fire in the northern boreal forest is that the forest will regenerate to approximately similar species composition and stem density as the pre-fire forest, known as the direct regeneration hypothesis (Ilisson and Chen, 2009). This is likely because the fire return interval is often too short to allow relay succession so post-fire species composition resembles pre-fire composition (Johnstone et al., 2010a). However, in northern conifer forests, post-fire regeneration densities may not always be adequate to maintain a closed canopy forest on site (Arseneault, 2001) while in boreal mixed species stands there is evidence that deciduous trees may form a greater component of the regenerating forest (Johnstone and Chapin, 2006). These transitions in the post-fire forest away from the pre-fire forest structure and composition are likely related to fire severity and pre-fire stand composition and age. For example, within pine dominated ecosystems, high severity burns have been linked to reduced regeneration in some (Lentile et al., 2005; Arseneault, 2001) but not all cases (Weber et al., 1987; de Groot et al., 2004). A confounding factor with fire severity is the age of the pre-fire forest, where young conifer stands may not regenerate as well as older conifer stands (Greene and Johnson, 1999) resulting in a shift in dominance to asexually regenerating deciduous trees (Johnstone and Chapin, 2006).

Jack pine (*Pinus banksiana* Lamb.) is a highly fire adapted species that regenerates rapidly after fire from an aerial seedbank of serotinous cones (Cayford and McRae, 1983). Each mature tree may hold up to 10 years of closed cones resulting in a large potential seed source post-fire (Greene and Johnson, 1999). There is a very narrow window of seedling recruitment after a fire with the majority of seedlings establishing immediately after the fire with 90% of seeds dispersed within 1 year (Greene et al., 2013) so regeneration immediately after a fire gives a good indication of longterm stand composition. The preferred seedbed for jack pine is exposed mineral soil and burnt humus (Chrosciewicz, 1974; Cayford and McRae, 1983; Herr and Duchesne, 1995). Post-fire regeneration densities of jack pine typically reach levels of over 10,000 seedlings per hectare, with examples of over 50,000 seedlings per hectare being common (e.g. Cayford and McRae, 1983; Weber et al.,

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1987; Chrosciewicz, 1988; de Groot et al., 2004). Given its regenerative adaptations to fire, jack pine is thought to be a resilient species able to withstand repeated disturbances. Jack pine often grows in mixed species stands in the boreal forest but on xeric, sandy sites jack pine usually occurs in pure stands with no other tree species present and represents the "climax" forest type in these areas (Beckingham and Archibald, 1996; Taylor and Chen, 2011).

Models of post-fire tree regeneration at the stand level are often developed after experimental fires which may not experience the same levels of burn severity as wildfires (e.g. Weber et al., 1987; de Groot et al., 2004). Other studies use chronosequences of forest development to model post-fire regeneration and succession but fire severity in these studies is often uncertain and variable (e.g. Arseneault, 2001; Greene and Johnson, 1999) and the assumptions for using chronosequences are often not met (Johnson and Miyanishi, 2008). At the landscape scale, differences in stand level regeneration are rarely quantified so it is not known how site specific regeneration failures may contribute to larger scale changes in ecosystem structure and composition.

The overall goal of this study was to determine the impact of fire severity and stand characteristics on jack pine regeneration immediately after fire in jack pine dominated boreal forest of Alberta, Canada. Specifically, we aim to: (1) determine how jack pine regeneration density is influenced by fire severity and stand age within individual stands and (2) quantify at the landscape scale the patterns of jack pine regeneration after fire. From a forest land management perspective, this study will allow for a better understanding of the range of potential successional trajectories and future forest compositions after fire in pure jack pine forests.

2. Methods

2.1. Fire description and study area

This study was based on the Richardson Fire (Fig. 1) which burned an area of 576,000 ha with a perimeter burn area of 658,000 ha from May to August 2011 and was the second largest documented fire in the history of western Canada (Canadian Forest Service, 2013a). After an initial human ignition on May 14, 2011, the fire spread upwards of 30 km per day on May 15–16th during a period of extreme fire weather. Of the 9200 hotspots recorded, 20% were observed during periods of extreme fire behaviour, where modelled head fire intensity was in excess of 10,000 kW m^{-1} and rates of spread were between 10 and 55 m min^{-1} (Canadian Forest Service, 2013b).

The Richardson Fire occurred mainly in the Athabasca Plain natural region of northeastern Alberta where the dominant vegetation is jack pine and the surficial geology is mainly aeolian sands giving rise to active dune complexes within the fire boundary (Downing and Pettapiece, 2006). Soils are classified dominantly as dystric brunisols (Soil Classification Working Group, 1998) with common understory vegetation consisting of *Arctostaphylos uva-ursi*, *Vaccinium myrtilloides* and *Cladina mitis* (Beckingham and Archibald, 1996). The southern and western fringes of the Richardson Fire are in the Central Mixedwood natural region which have more trembling aspen (*Populus tremuloides*) and white spruce (*Picea glauca*) mixedwoods (Fig. 1) but our study is focused on the portion of the fire located in the jack pine dominated Athabasca Plain. The average January temperature (based on the Fort McMurray climate normals from Environment Canada) is -19 °C, the average July temperature is 17 °C. Median annual precipitation is 455 mm, with 34% falling as snow. Average annual potential evaporation is 480 mm (Ozoray et al., 1980), with potential evaporation exceeding annual precipitation in 69% of years indicating that this region is on the climatic edge between the closed canopy boreal forest and non-continuous forest of the aspen parkland (Hogg and Hurdle, 1995).

2.2. Field sampling design

Initial field scouting immediately after the Richardson Fire in fall 2011 and spring 2012 indicated a great deal of variability in post-fire jack pine regeneration, fire severity and pre-fire stand

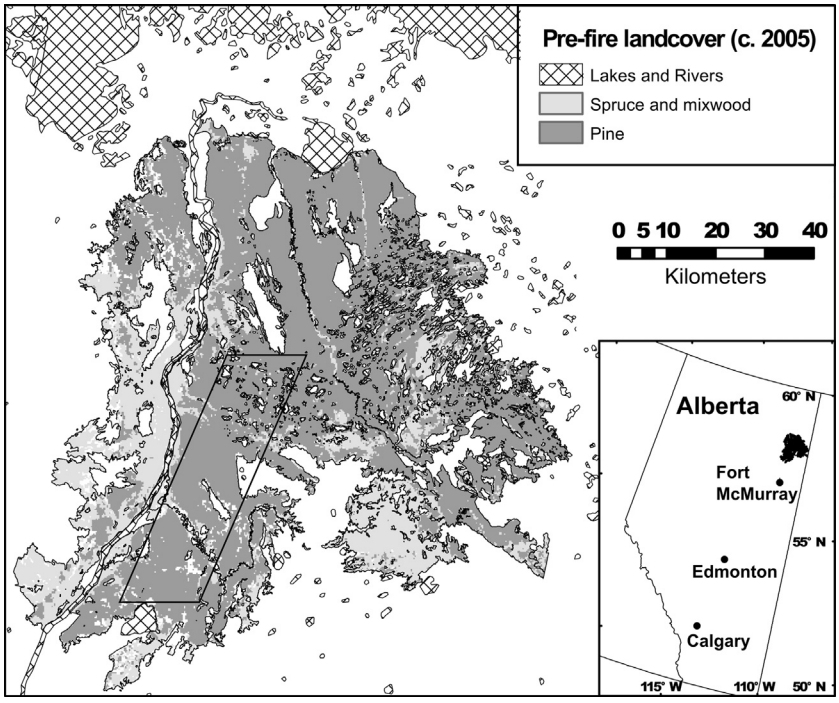

Fig. 1. Map of the 2011 Richardson Fire in northeastern Alberta, Canada and the pre-fire stand composition within the burn perimeter. Boundary of the sampling area is the boxed area.