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Fire and forest recovery on seismic lines in sandy upland jack pine (*Pinus banksiana*) forests

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ABSTRACT

Networks of narrow linear (~3–12 m wide) forest disturbances used for petroleum exploration (seismic lines) are common throughout Alberta's boreal forest. These 'seismic' lines have often failed to recover trees decades after their initial disturbance, especially within treed peatland and jack pine (*Pinus banksiana*) forests. This has led to regional increases in forest fragmentation contributing to declines in threatened woodland caribou. Restoration of seismic lines to forests is now a top priority for conservation and recovery of woodland caribou, but are expensive and often ignore the occurrence of wildfires that may destroy restoration investments (planted trees), yet also recruit trees. This is especially relevant to jack pine forests that burn more frequently than other forests and depend on moderate to high intensity fires to release seeds *en masse* from their serotinous cones. Although much is known about jack pine tree recruitment following fire, little is known about patterns of tree recovery on seismic lines and how this varies with fire severity, line width (forest gap size), and line orientation. Here we examine natural tree recovery across a gradient in fire severity (defined as percent overstory tree mortality) with different seismic line characteristics (forest gap width and orientation), as compared to adjacent forest stands, in jack pine forests 5-years post-fire in northeast Alberta, Canada. Overall, jack pine regeneration was consistently 2-fold higher on seismic lines compared to adjacent burned forests with stem density increasing with fire severity in both sites, especially when fire severity was greater than 40%. We suggest that the observed increases in tree regeneration on seismic lines may be due to (1) removal of biomass and exposure of mineral soils on seismic lines creating more favorable conditions for jack pine seeds and seedlings; and/or (2) increases in available light resulting in better growing conditions and survival for this shade-intolerant species. Finally, we suggest that natural recovery (passive restoration) of seismic lines should be expected post-fire in jack pine stands and thus active restoration of these sites through silviculture and tree planting may not be the wisest use of limited restoration dollars if fires are locally common.

1. Introduction

Oil sands exploration and extraction in northern Alberta, Canada have affected the boreal forest in a number of ways, particularly through fragmenting forests with roads, pipelines, transmission lines, and drilling well pads. However, the largest anthropogenic contributor of forest fragmentation is seismic lines (Arienti et al., 2009; Schneider et al., 2010) often reaching densities of 10 km/km^2 (Lee and Boutin, 2006). Seismic lines are narrow (3–12 m) linear corridors (Fig. 1) designed in a network of repeating corridors where trees are removed for the purpose of petroleum exploration (seismic assessments). These disturbances can simplify microtopography and compact the soil surface leading to failures in tree regeneration (Lee and Boutin, 2006; Caners and Lieffers, 2014; van Rensen et al., 2015; Lieffers et al., 2017). This has contributed to changes in wildlife populations and more broadly biodiversity (Timoney and Lee, 2001; Hooper et al., 2005; Lee and Boutin, 2006; Kemper and Macdonald, 2009a; 2009b; Caners and Lieffers, 2014). The most high-profile species-at-risk in Canada's boreal forest are woodland caribou (Environment Canada 2012). Although seismic lines are generally avoided by caribou (James and Stuart-Smith, 2000; Dyer et al., 2001, 2002), they are favored by wolves increasing their movement efficiency in caribou habitat (James and Stuart-Smith, 2000; Latham et al., 2011). This can reduce survival rates of caribou and as a consequence contribute to caribou population declines (James and Stuart-Smith, 2000; Dyer et al., 2001, 2002; Latham et al., 2011). Mitigation efforts are now extensively being used to address this issue by restoring tree growth on seismic lines or, over shorter periods, reducing wolf use of lines by adding structural barriers to movement. Long-term restoration goals hinge, however, on recovery of trees on seismic lines.

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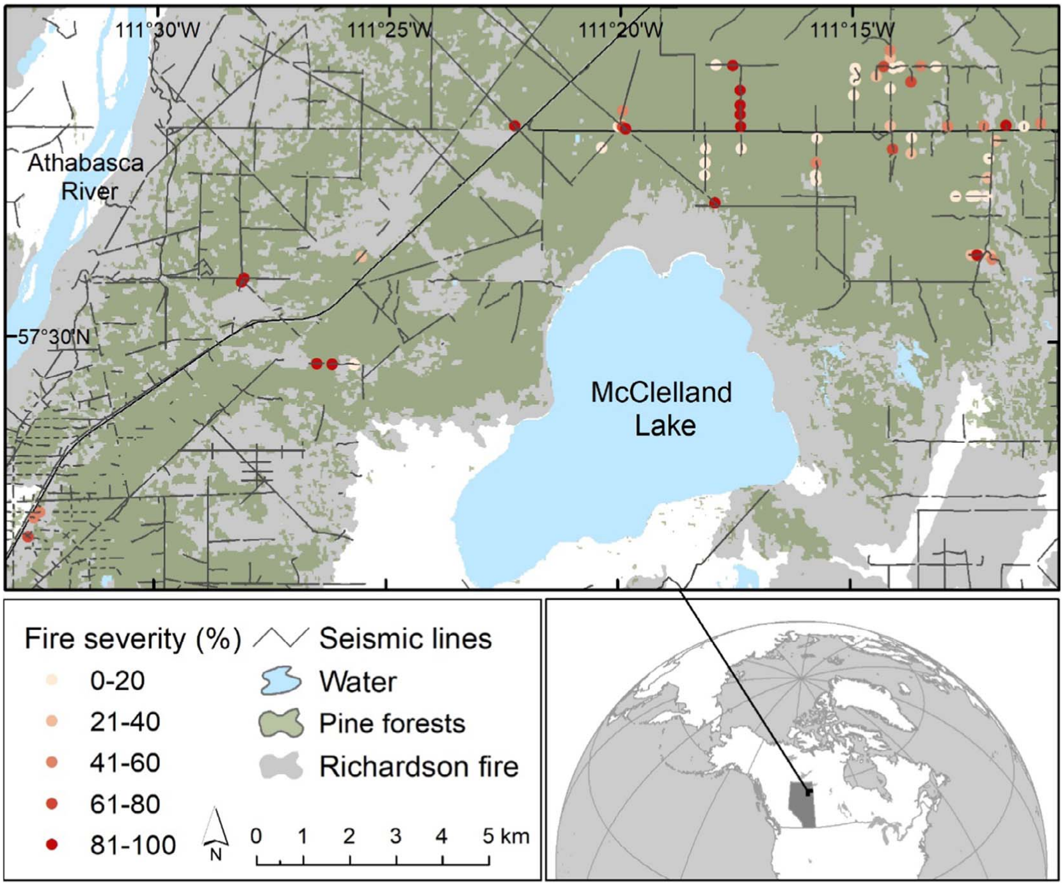

Fig. 1. Location of study area in northeast Alberta, Canada (inset map), the location of study sample sites relative to fire severity as measured by overstory tree mortality (light red to red circular symbols representing the fire severity gradient), location of seismic lines, location of 2011 Richardson fire in gray, and pine forests in dark green for where it burned (most places) or in very few location light green where unburned. Each site represents a pair of plots with one being on the seismic line and the other in the adjacent forest stand. Note that some sites were within 200–400 m of each other when fire severity levels differed, stands varied, or there were gaps in the seismic line disturbance.

Costs of these active restoration treatments are high averaging $12,000 (CAD) or more per km of seismic line with treatments involving site preparation (mounding, ripping) and tree planting. Conversely, passive restoration strategies for seismic lines that rely on natural rates of reforestation (i.e., leave-for-natural) have no direct costs, but depend on extended timeframes of recovery (Lee and Boutin, 2006; van Rensen et al., 2015). Understanding where reforestation is occurring is therefore a priority in planning and prioritizing the location of restoration activities. Wildfires, the largest contributor to boreal forest disturbance, are one possible leave-for-natural passive form of restoration, but also represent a risk to investments in active restoration treatments where tree planting occurs. Much less is known, however, on how wildfires affect recovery rates of seismic lines despite being a major driver of successional changes in the boreal forest and a risk or opportunity for restoration.

Seismic line disturbances in xeric sandy jack pine (*Pinus banksiana*) forests are one of the two forest-types in northeast Alberta characterized by being in a state of arrested succession (van Rensen et al., 2015). Yet this may be an overgeneralization that is dependent on the time scale examined since jack pine cones are serotinous and typically release their seeds *en masse* only after moderate to high intensity fires (Ahlgren and Ahlgren, 1960; Cayford and McRae, 1983; Lamont et al., 1991) with fire return intervals for jack pine forests in northeast Alberta typically being 28–54 years (Carroll and Bliss, 1982; Larsen, 1997; Larsen and MacDonald, 1998). A more informed test of whether these seismic lines will naturally regenerate is to therefore examine patterns of post-fire recovery. If fires promote recovery of seismic lines in conditions similar to adjacent stands (a form of passive restoration), it would have major implications for planning restoration activities in the boreal forest even if fires are not directly used as active restoration treatments.

In this paper we examined recovery dynamics on seismic lines and adjacent paired forest controls in jack pine forests by fire severity (percent overstory tree mortality), forest stand conditions (age, height, and basal area), and seismic line characteristics (forest gap width and orientation). Specifically, we tested whether fire naturally recovers seismic lines or whether other factors (small gap widths, simplified microtopography, etc.) restrict regeneration compared to adjacent paired forest controls. On the one hand, seismic lines post-fire may provide more exposed mineral soil, sunlight, and wind (seed dispersal), as well as less competition thus favoring tree regeneration for shade-intolerant species like jack pine. On the other hand, micro-terrain on seismic lines may be simplified during construction of seismic lines offering fewer microsites for conditions that would favor tree recruitment following fire, especially under drier post-seed dispersal conditions. We address these questions by examining jack pine and other tree regeneration 5-years post fire on seismic lines compared to adjacent forests in northeast Alberta, Canada.

2. Methods

2.1. Study area

The study area consists of 100 km^2 of boreal forests within the Regional Municipality of Wood Buffalo and the Athabasca Oil Sands of northeastern Alberta. It is approximately 115 km north of Fort McMurray and within a 15-km radius of the west and north ends of McClelland Lake (57°31′56″N, 111°21′40″W, Fig. 1). The area lies on

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