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Edge influence of low-impact seismic lines for oil exploration on upland forest vegetation in northern Alberta (Canada)

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ABSTRACT

Low-impact seismic (LIS) techniques were developed to reduce the environmental footprint of oil exploration. Though relatively narrow (~2–3 m) and constructed with light-weight equipment, these lines cause forest fragmentation, and with their high density and potential edge influence extending into adjacent forest, their impact may be considerably underestimated. We assessed the effects of 3- to 4-year-old LIS lines in upland coniferous sub-boreal forests in northwestern Alberta (Canada) by investigating the distance of influence from the LIS line centre, through the edge and into the adjacent forest on vascular and non-vascular plant species diversity and cover and on several environmental factors. We also assessed whether cardinal orientation of the edge affects influence on plants and environmental factors. Edge orientation had no effect on extent of edge influence on plants or environmental variables, but distance from seismic line edge did. Species diversity of herbaceous plants was lowest from the seismic line edge up to 15 m into the adjacent forest, when compared to mid- (25 m) and far-interior (75 m) forest. In contrast, cover was lower 5 m from the seismic line edge in comparison to far-interior forest, but conditions on the seismic lines did not differ from the seismic line edge or any sampled distance up to 75 m from the edge. Non-vascular species had lower diversity and cover on the seismic lines and along the edges in comparison to any distance away from the edge. There was no effect of distance from the seismic line edge on live woody plants, but deadwood was more frequently encountered near the seismic line edges in comparison to interior forest. Soil temperature was higher on the seismic lines and along the line edges whereas soil moisture on the seismic lines was about twice as high as at the edges and adjacent forest. Seismic lines and edges also received more light than the forest near the edge, but not more than the far-interior forest. With edge influence detectable up to 15 m from edge 3 to 4 years post-construction, long-term and regular monitoring of LIS lines is recommended, as active management and remedial reclamation actions might be required to bring the recovery of these disturbances on the right trajectory.

1. Introduction

Edges of two adjacent habitats can present a distinct set of environmental conditions resulting from the influence and interaction of biotic and abiotic factors associated with both habitats (Murcia, 1995). The distance (extent) of edge influence into adjacent habitat, or the change along the edge-to-interior gradient, as well as the magnitude, or the degree of change along that gradient, are the two main parameters by which edge influence is assessed (Harper and Macdonald, 2001). The altered conditions created on edges may extend into the adjacent habitat and may change plant community dynamics, including diversity, abundance and composition, further affecting the unique edge environment and maintaining ongoing edge dynamics (Harper et al., 2005).

Edge influence on forest plant communities has been well-documented in a wide variety of scenarios and climates, including different forest types such as: sub-tropical and tropical (Laurance et al., 1998; Didham and Lawton, 1999; Prieto et al., 2014), temperate (Brothers and Spingarn, 1992; MacQuarrie and Lacroix, 2003), sub-boreal (Burton, 2002), and boreal forests (Harper et al., 2004, 2016; Gignac and Dale, 2005, 2007), and different edge types such as clear-cut (Chen et al., 1995; Burton, 2002; Dupuch and Fortin, 2013), fire (Harper et al., 2004, 2014), lakeshore (Harper and Macdonald, 2001), plantations (Euskirchen et al., 2001), agricul-

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tural and pasture (Gehlhausen et al., 2000), and linear disturbance edges such as gas pipeline and powerline edges (Prieto et al., 2014; Eldegard et al., 2015; Lima do Couto-Santos et al., 2015). However, studies on edge influence of seismic lines in boreal ecosystems on forest vegetation have been limited and not recent, or unpublished in peer-reviewed literature (Revel et al., 1984; Bella, 1986; MacFarlane, 2003).

In the Canadian province of Alberta, seismic line construction continues at a high pace, especially on the extensive landbase overlaying *in situ* bitumen deposits (CAPP, 2013). Alberta is dominated by forests that cover about 60% (~38 million ha) of the landbase (AFPA, 2016), and much of it has been disturbed and fragmented by industrial forestry, agriculture, oil and gas extraction, and transportation and communication corridors. In recent decades, an increasing proportion of annual anthropogenic disturbances has been caused by oil and gas exploration and development, including construction of seismic lines, which are used to identify and map oil and gas geological structures prior to drilling (EMR, 2006). Conventional seismic line construction involved wood clearing of 5–10 m-wide strips using heavy machinery. These lines have experienced very low recovery success over the past few decades. For example, in the Western Boreal Plains ecozone in Alberta only 8.2% of conventinal seismic lines have recovered to >50% cover of woody vegetation 35 years after their construction (Lee and Boutin, 2006). Conventional seismic lines in early successional stages still intersect much of the land in Alberta. By 2001, the total length of seismic lines in the province was estimated at 1.5–1.8 million km (Timoney and Lee, 2001), and the mean density of conventional seismic lines in northeastern Alberta in 2006 was 1.5 km km^{-2} (Lee and Boutin, 2006). With the rapidly increasing level and intensity of industrial activity over much of the province, maintenance of ecosystem integrity whereby human activity does not compromise the natural functioning of the ecosystem can only be achieved through science-based practices to sustainably manage landscapes, including reduction of the industrial footprint and improved restoration of disturbed areas.

An example of best practices to reduce industrial footprint is the development of low-impact seismic (LIS) techniques (CAPP, 2004). The small and light-weight equipment used to construct LIS lines is thought to cause less soil disturbance, while the narrow meandering nature of the lines is thought to better emulate natural variation patterns and low-intensity natural disturbance events, potentially maintaining more natural movement patterns and interactions of wildlife (CAPP, 2004). However, research addressing the responses of vegetation to LIS lines, and specifically, the extent of LIS lines edge influence on vegetation in adjacent forest, has been limited, especially for lines constructed in the past decade. Early versions of LIS lines originating in the mid-1990s were relatively wide (~5 m), cleared with light-weight bulldozers, and were likely frequently seeded with agronomic grasses (MacFarlane, 2003). Newer LIS lines are usually ~1.5–3.0 m wide, cleared with light-weight and compact mulcher equipment, and no longer seeded with agronomic species (EMR, 2006; AECOM, 2009).

Although recent LIS lines are narrow, their rapidly increasing utilization, especially on *in situ* leases where lines are often only a few tens-of-meters apart and gridded over large areas, they may exert substantial edge influence that may greatly enhance their overall footprint (Porensky and Young, 2013). Assessment of edge influence adjacent to LIS lines (and to other industrial disturbance features) is often neglected as typically the focus is on the directly disturbed parts of the landbase. Nonetheless, measurement of edge influence is necessary to evaluate the full range of impacts of industrial activities on abiotic and biotic factors, and to ensure that integrated land management policies and practices are built on a robust science foundation.

Impact on abiotic factors leading to altered environmental conditions on the edges may affect plant responses, and may contribute to changes in species composition along the distance gradient from the line edge, since different plant species have different ranges of tolerance, physiological adaptation and preference for their optimal growing conditions. Eldegard et al. (2015) reported a wide range of responses for various vegetation types along the gradient of the powerline clearing-forest edges in Norway. Competitive advantage may shift under altered environmental conditions, benefiting different types of plant species.

It has been shown that edges in boreal forests of Canada and Europe do not have as strong, extensive and persistent influence on vegetation as in tropical and temperate ecosystems, as boreal forests are inherently heterogeneous and well-adapted to disturbances (Harper et al., 2015). However, in terms of anthropogenic edges, meta-analyses of edge influence by Harper et al. (2015) were predominantly for edges along cut-blocks and not linear disturbances, which create more edge per unit area than other anthropogenic disturbances due to their high density and length, potentially having a much larger impact at the landscape level in boreal forests (CAPP, 2004; Jansson et al., 2011).

We argue that the long, narrow corridors created by seismic lines are not necessarily analogous to cut-blocks. Linear features may be less subjected to changes in microclimatic conditions at the local scale than are more exposed polygonal edges such as those created by forest harvest. However, Pohlman et al. (2007) observed significant effect of linear disturbances on microclimatic factors - light intensity, air temperature, and vapor pressure deficit were elevated near the edges. With increased light intensity, edges may also be warmer and drier and experience increased wind, and these gradients can penetrate hundreds of metres into the adjacent forest (Chen et al., 1995; Alignier and Deconchat, 2013; Crockatt and Bebber, 2015). Furthermore, differences in wind intensity may affect windthrow and the amount of deadwood present on the ground along the edges (Chen et al., 1995; Burton, 2002) which may have a significant influence on other micro-environmental conditions, thereby affecting growth and abundance of plant species. Ground substrates, including deadwood, provide media for plant establishment and growth, and different plant species may vary in their preference of rooting substrate. Additionally, the orientation of edges affects the sun angle, which may affect microclimatic factors and vegetation responses to edges (Chen et al., 1995; Burton, 2002; Hylander, 2005).

The objective of this study was to assess the edge influence of 3- to 4-year-old LIS lines on vegetation in adjacent upland coniferous sub-boreal forest of Alberta. We investigated the extent of distance of edge influence of LIS lines along transects running from the line edge into adjacent forest by examining plant species diversity and cover (abundance) and several environmental variables (soil temperature, soil moisture, light levels, and ground substrate cover) that could explain patterns of plant responses. Plant and environmental responses on seismic lines were also assessed to put the potential edge influence in the context of their disturbance source — the LIS line itself. We included LIS lines with N–S and E–W orientations to examine whether edge orientation affects edge influence.

2. Materials and methods

2.1. Study area

The Swan Hills region (elevation ~1300 m) of west-central Alberta is located in the Lower Cordilleran Ecozone (Beckingham et al., 1996). The region consists of a mosaic of upland coniferous and mixedwood forests, and poorly drained peatlands (Griffiths