Biological Conservation 217 (2018) 173–180

Contents lists available at ScienceDirect

Biological Conservation

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

Localized disturbances from oil sands developments increase butterfly diversity and abundance in Alberta's boreal forests

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ARTICLE INFO

Keywords:
Corridor
Habitat amount
Habitat fragmentation
Habitat diversity
Lepidoptera
Oil sands developments

ABSTRACT

Understanding species responses to changes in habitat is a primary focus of biodiversity conservation, especially when assessing widespread anthropogenic disturbance. Extraction of Alberta's subterranean oil sands by wells requires extensive networks of cleared linear disturbances ("in situ" extraction) that result in widespread, but localized increases in early seral habitats. Little is known about biodiversity responses to these disturbances, especially for invertebrates. Here, we investigated how butterflies responded to in situ oil sands developments in the boreal forests of Wood Buffalo region, Alberta, Canada. To assess the magnitude of change associated with different disturbance types, we compared abundance and diversity of butterflies in undisturbed forests with those observed in 3-m and 9-m wide cleared corridors (seismic lines), 60 × 60 m clearings (well pads), and roadside verge habitat. The butterfly assemblage was evaluated based on disturbance type and three measures of landscape change: amount of early seral habitat, edge density, and diversity of natural habitats. Species richness was twice and abundance three-times higher in larger disturbances than in controls, with the narrowest corridors not differing from controls. A model using disturbance type, edge density, and habitat diversity explained 62% of assemblage variation, with the type of disturbance explaining 47%. Higher butterfly abundance and diversity occurred in localized early seral sites, even on 9-m wide corridors, while surrounding landscape characteristics had little effect. Results are consistent with previous studies finding stronger responses in vertebrates to larger disturbances associated with oil sands, confirming that narrower corridors mitigate the effects of oil sands exploration.

1. Introduction

Loss and degradation of natural habitats represent major threats to terrestrial ecosystems, but the full implications of these factors for biodiversity are far from understood (Fahrig, 2013, 2017; Ewers and Didham, 2006; Hanski, 2015). As energy demands for humans have increased, so has the amount of disturbance to ecosystems (Northrup and Wittemyer, 2013). The role of unconventional oil reserves, such as oil sands, in meeting these energy demands is growing rapidly despite little information on their environmental impacts (Northrup and Wittemyer, 2013). To date, surface mining of oil sands in Alberta has received the most attention, despite representing only 3% of the total 142,000 km^2 oil sands reserve (Mossop, 1980; Rooney et al., 2012). Most oil sands are available only through underground extraction (wells) using "in situ" extraction techniques that we focus on here (to follow, "oil sands developments").

Unlike oil sands surface mining, where bitumen is removed from the near surface (Rooney et al., 2012), these oil sands developments do not cause complete loss of habitat during mining, but rather widespread disturbance of forests to early seral vegetation. This is partly due to extensive exploratory seismic assessments that are used to locate the extent of underground oil (bitumen) reserves. Narrow corridors ("seismic lines") are cleared into forests using a grid pattern resulting in localized, but dense networks of disturbances (Fig. 1). The 2-dimensional distribution of oil is first assessed using 6–10 m wide corridors with densities typically < 5 km/km^2 (2D seismic lines). Where economically viable oil sands are found, narrower (2–5.5 m), but much denser (up to 40 km/km^2) corridors, are used to map more precisely the depth and thickness of the oil reserve (3D seismic lines) (Lee and Boutin, 2006; Tigner et al., 2015). The narrower corridors are often referred to as "low-impact" despite few studies testing their difference. If oil deposits are of sufficient size for extraction, well pads, roads, and pipelines are added, thereby increasing the anthropogenic footprint. Despite more recent use of best-management practices (e.g. reduced corridor width), and the fact that these disturbances often represent early seral forest conditions with vegetation, these disturbances can

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https://doi.org/10.1016/j.biocon.2017.10.022
Received 7 April 2017; Received in revised form 5 October 2017; Accepted 18 October 2017

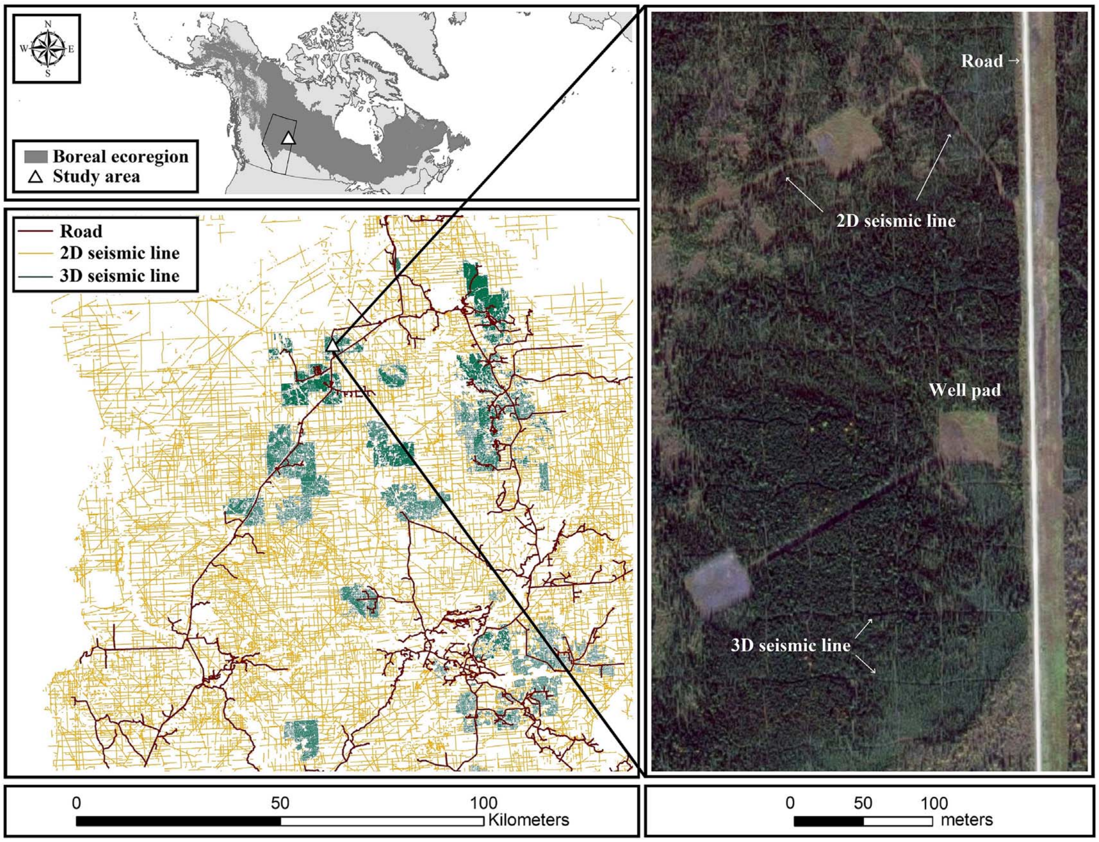

Fig. 1. Map of study area. Top left: Canadian boreal ecoregion, Alberta boundary, and location of study area. Bottom left: the Wood Buffalo Region, where the Alberta oil sands extraction occurs, shows high levels of forest fragmentation due to oil sands exploration and development. 3D seismic lines are spaced as close as a 50 m apart; Right: example detail of the study area. See Appendix A1.2 for representative ground photographs of disturbance types.

persist for decades due to failures in tree recruitment (Lee and Boutin, 2006; van Rensen et al., 2015).

There are a number of major gaps in our understanding of the effects of oil sands developments. Forest recovery of conventional corridors (6–10 m wide) to more suitable forest conditions is known to be more delayed within wet than dry areas, with models predicting > 30% of corridors in treed peatlands failing to recover to a 3-m tree height over a 50-year period (van Rensen et al., 2015). The effects on individual plant species are, however, largely unknown. To date, most studies have assessed behavioral responses of vertebrates with mammals and birds either avoiding seismic line corridors (Bayne et al., 2005; Machtans, 2006; Tigner et al., 2015), using them (Tigner et al., 2014), or responding neutrally to their presence (Machtans, 2006). The most influential example is that of woodland caribou (*Rangifer tarandus caribou*, L.), a threatened species in Canada that avoids seismic lines, roads, and well pads (Dyer et al., 2001). Because gray wolves (*Canis lupus*, L.) increase their movements along these linear features (Latham et al., 2011), it is hypothesized that forest corridors negatively affect caribou populations through increased predation. Recovery strategies include restoration of seismic lines with costs of habitat protection for caribou estimated at $150 billion (Hebblewhite, 2017). Although behavioral changes in animal species have been widely reported, little is known about whether these linear features affect population dynamics (but see Tigner et al., 2015). Even less is known about how different types of oil sands disturbances affect invertebrates. Because this group depends on more localized environmental conditions (Stein and Kreft, 2015), stronger responses are expected.

Here, we investigate the effects of different forest disturbances associated with oil sands developments on butterfly diversity and abundance in northern Alberta's boreal forest. Specifically, we use the variation in the butterfly assemblage as a proxy to measure the magnitude of disturbance associated with oil sands developments. Arthropods have been previously investigated to assess the effects of anthropogenic disturbance in forest ecosystems worldwide (Niemelä, 1997; Maleque et al., 2009), and several studies demonstrated responses in butterflies to forest disturbance in temperate and boreal forests (Niemelä, 1997; Maleque et al., 2009; Bubová et al., 2015). Butterflies are well-suited for examining responses to these peculiar disturbances as they are sensitive to environmental change at local spatial scales, to which they demonstrate rapid responses in populations (Dover and Settele, 2009; MacDonald et al., 2016). We posed two questions: (1) How do butterflies respond to different types of oil sands disturbance?; and (2) What is the relative contribution of these disturbances to compositional differences in butterflies? To address these questions, we sampled butterflies within four different types of oil sands disturbances along with adjacent undisturbed forests (controls), to compare butterfly diversity and abundance. We then compared the variation explained in the butterfly assemblage by the disturbance type where butterflies were sampled with the variation explained by amount of early seral habitat, density of edges, and diversity of habitat measured on the landscape surrounding each sampling sites.

Because boreal plant diversity is higher in early seral stages than in mature forest stands (Pykälä, 2004), and butterflies depend on the plant community for larval host plant and nectar sources (Dennis et al., 2006), we expected lower butterfly diversity and abundance in mature boreal forests than in early seral forests. This ecosystem is shaped by periodic wildfire disturbance and has generally few, if any, forest specialist species (Weber and Stocks, 1998), also for butterflies (Bird et al., 1995). Consequently, we hypothesized that increasing amounts of early seral conditions following forest disturbance would promote butterfly diversity and abundance, although the scale at which these disturbances altered the assemblage was unknown. Forest clearings sustain