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Short-term response of *Cladonia* lichen communities to logging and fire in boreal forests

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ABSTRACT

Fire is the major disturbance agent in boreal forests that initiates forest regeneration and succession, and plays a major role in determining the composition of terricolous lichen communities. In recent decades however, logging has become an important disturbance agent in boreal forests. In this context, growing concerns about logging effects on endangered species such as woodland caribou (*Rangifer tarandus caribou*) has emerged and drawn attention on how reindeer lichens (i.e. *Cladonia arbuscula*, *Cladonia mitis*, *Cladonia rangiferina*, *Cladonia stellaris*, and *Cladonia stygia*) respond to logging and fire given their importance as winter forage for caribou. We compared critical lichen habitat factors (i.e., forest floor thickness, tree height, and canopy closure) between fire and logged sites and evaluated how *Cladonia* lichen species richness, biomass, and ground cover were related to these habitat factors in the first decades following disturbance. We found no significant differences in habitat factors and no significant differences in lichen species richness or ground cover between logged and fire sites. However, *Cladonia* lichen biomass was significantly higher following logging. These results support the hypothesis that *Cladonia* lichens can persist following logging and suggest that forestry practices that include in their toolbox winter harvesting or machinery traffic restricted to specific trails are likely to preserve undisturbed forest floor habitat conditions with source populations of lichens.

1. Introduction

Fire is considered the major natural disturbance in boreal forests (Payette, 1992; Bergeron et al., 2001). Fires are recurrent phenomena (Heinselman, 1981; Morneau and Payette, 1989; St-Pierre et al., 1992), which initiate forest regeneration and succession (Heinselman, 1981; Payette, 1992), and play a major role in determining the distribution and composition of plant communities in boreal forests (Bergeron and Dubuc, 1989; DeGrandpré et al., 1993; Kenkel et al., 1997). Black spruce stand dynamics are mainly associated with fires of variable frequency, severity and size (Bergeron et al., 2001). Severe fires play an important role, killing ground vegetation and reducing the thickness of the organic layer, hence creating microsites favorable for the establishment of various plant species (Heinselman, 1981; Viereck, 1983). For instance, the exposition of well drained and/or acidic mineral soil following fire provides an ideal substrate for the post-fire colonization of terricolous lichens (Kershaw, 1977). Fire also creates openings in closed-crown forests and contributes to the establishment or renewal of the terricolous lichen mat (Schaefer and Pruitt, 1991; Coxson and Marsh, 2001; Dunford et al., 2006). Consequently, fire has an important effect on both the distribution and abundance of terricolous lichen species in boreal ecosystems (Coxson and Marsh, 2001; Zouaoui et al., 2014), which in turn provide important winter forage for large herbivores, such as the woodland caribou (*Rangifer tarandus caribou*) (Webb, 1998; Lantin, 2003; Dunford et al., 2006; Joly et al., 2010; Lesmerises et al., 2011) which mainly feed on reindeer lichens (i.e., *Cladonia arbuscula*, *Cladonia mitis*, *Cladonia rangiferina*, *Cladonia stellaris* and *Cladonia stygia*).

Over the past few decades, boreal forests have undergone a profound transformation due to human activities, particularly logging which is now the dominant disturbance agent (Burton et al., 2010). As a result, in several regions the area altered by natural disturbances is smaller than that disturbed by logging (Bergeron et al., 2006; Drapeau et al., 2009). Furthermore, logging has been identified as a potential threat to terricolous lichen communities (Goward, 1994; Ryan, 1996; Botting and Fredeen, 2006), because of the removal and disturbance of the lichen mat and modification of the soil microclimate (Dahlman and Palmqvist, 2003;

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Gaio-Oliveira et al., 2004). More specifically, logging is thought to negatively affect terricolous lichen establishment through inadequate shade from the remaining trees, slash deposition as well as a deficient amount of exposed mineral soil (Lesica et al., 1991; Frisvoll and Presto, 1997; Miège et al., 2001; Waterhouse et al., 2011). Indeed, in a study on the influence of ground substrate on lichen establishment conducted in Sweden, Roturier et al. (2007) found that lichen cover was significantly higher on bare mineral soil than on other types of substrate, including woody substrates.

In the North American boreal forest, the growing concern of logging effects on biodiversity, particularly on endangered species such as the woodland caribou (Chubbs et al., 1993; Environment Canada, 2011; Rudolph et al., 2012), has drawn attention on how terricolous lichens, especially reindeer lichens, respond to logging and fire in the boreal forest given their importance as winter forage for caribou (Lantin, 2003; Dunford et al., 2006; Joly et al., 2010; Lesmerises et al., 2011). These studies produced, however, conflicting results. Some concluded that soil drying caused by logging could favor lichen growth on sites normally dominated by mosses (Harris, 1996; Racey et al., 1996; Webb, 1998; Johnson et al., 2014), whereas other studies found that the vigorous response of tree regeneration following logging could be detrimental to lichen growth (Coxson and Marsh, 2001; Desponts et al., 2002; Newmaster and Bell, 2002). More recently, Boudreault et al. (2013) suggested that canopy opening after partial cuts provided better growing conditions for terricolous lichens (through increased light and moisture reaching the forest floor), which helped maintain pre-established lichen cover at levels comparable to those in old growth forests. Although the effects of logging on lichen communities remain unclear, silvicultural treatments that change the structural complexity of forest have the potential to create different microhabitats that influence the composition of lichen communities (McMullin et al., 2010).

Furthermore, both lichens and bryophytes are a major component of the forest floor communities in boreal forests (Esseen et al., 1997) where they form extensive mixed-species mats. Their relative abundance in mixed-species mats has been found to vary with light intensity and moisture, with lichens frequently overgrowing bryophytes under conditions of high light intensity and low moisture (Morneau and Payette, 1989; During and van Tooren, 1990; Sedia and Ehrenfeld, 2003). Therefore, the composition of the terricolous lichen community is likely to vary with the light and moisture conditions prevailing after fire or logging.

In the last decades, the concept of forest ecosystem management based on natural disturbances has generated lots of interests as it is considered key to the conservation of biodiversity as well as to the preservation of ecosystem structure and functions (Gauthier et al., 2009). In this context, prescribed burning has been considered an appropriate management option in boreal forests to emulate the effects of fire on soil chemistry and stand productivity (Scheuner et al., 2004; Renard et al., 2016). However, before considering prescribed burning as an appropriate management option for lichens (and hence for the woodland caribou), it is of the utmost importance to better understand the response of terricolous lichens to logging and fire.

In this study we compared post-fire and post-logged *Cladonia* lichen communities (with a special focus on reindeer lichens) in the boreal forest of Québec, Canada. More specifically, we analyzed the biomass and ground cover of reindeer lichen and other *Cladonia* species in young (4–13 years, i.e., before complete canopy closure) black spruce stands following logging and fire. We first compared critical lichen habitat factors (i.e., forest floor thickness, tree height, and canopy closure) between fire and logged sites and then evaluated how lichen biomass and ground cover are related to these habitat factors following fire or logging. Then, because bryophytes co-occur with lichens within mixed-species mats and because both group of species may respond differently to particular light and moisture conditions prevailing after fire or logging, we also compared their post-disturbance ground cover. Ultimately, this study aimed at determining if fire and logging had similar effects on *Cladonia* species biomass and ground cover.

2. Materials and methods

2.1. Study regions

Prior to field sampling, potential study sites were first selected using forest maps and then ground truthed. With this method, we selected five study sites. The five study sites were located in three different regions of boreal Québec. Three sites were located in the black spruce (*Picea mariana* [Mill.] BSP)-feathermoss (*Pleurozium schreberi* [Brid.] Mitt.) bioclimatic domain and two sites were in the balsam fir (*Abies blasamea* [L.] Mill.)-white birch (*Betula papyrifera* Marsh.) bioclimatic domain (Robitaille and Saucier, 1998) (Fig. 1). Prior to disturbance the five study sites were dominated by black spruce. Sites were selected in order to pair logged and burnt stands occurring in similar ecological conditions and that were disturbed at similar time periods (Table 1). The regions where these sites were located are characterized by large crown fires that kill the majority of trees and the surface vegetation (Bergeron et al., 2002; Jasinski and Payette, 2005). Before the mid-1990's, stands were logged by clearcutting, but this technique has since been replaced by cut with protection of regeneration and soils (CPRS). CPRS consists of logging all commercial trees (diameter at breast height >9.1 cm) with machinery traffic restricted to parallel trails that cover approximately 25% (33% prior to March 2001) of the logged area (MRNFQ, 2003). Trails are separated by "protection strips" in which only commercial stems ($\geqslant$9.1 cm) are logged, leaving pre-logging tree regeneration.

Villebois (VB) region – The site in this region (48°58′–49°50′N and 79°01′–79°30′W) was located approximately 100 km north of Villebois (Fig. 1), in the Clay Belt physiographic region. This region is characterized by a flat topography and is underlain by Cochrane till, a compact till made up of a mixture of clay and gravel, created by a southward ice flow approximately 8000 years BP (Veillette, 1994). Thick (>30 cm) organic deposits are found in many locations. According to the nearest weather station (Joutel, Québec), the average annual temperature was 0.0 °C and average annual precipitation was 909 mm, with 35% falling during the growing season, from 1981 to 2010 (Environment Canada, 2015). The average number of degree-days (>5 °C) was 1241, and the frost-free season lasts about 60 days; frost occasionally occurs during the growing season. Fire frequency in the study area has diminished from a 100-year cycle to an approximately 400-year cycle since the little Ice Age (ca. 1850; Bergeron et al., 2004). The site consisted of a stand burned in 1997 and an adjacent unburned stand logged by CPRS in 1997, located 5 km apart. Pre-disturbance conditions of both stands corresponded to mature forest stands (>120 years) given stand age estimates from forest cover maps. Stands presented the thick organic layer typical of productive forest sites in this region (Lecomte et al., 2005), but were not true peatlands.

Lebel-sur-Quévillon (LB) region – There is one site in this region (48°25′–49°00′N and 76°20–76°79′W) located 50 km southeast of Lebel-sur-Quévillon (Fig. 1), made up of two stands approximately 10 km apart: a stand burned in 1995 and a nearby stand logged by CPRS in 1997. It is characterized by a flat topography with gently rolling hills, underlain by glaciolacustrine and undifferentiated till surficial deposits (Robitaille and Saucier, 1998). According to the nearest weather station (Lebel-sur-Quévillon, Québec), the average annual temperature was 1.0 °C and average annual precipitation was 928 mm, with 35% falling during the growing season, from