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Early response of ground layer plant communities to wildfire and harvesting disturbance in forested peatland ecosystems in northern Minnesota, USA

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ABSTRACT

A rare, stand-replacing fire in northern Minnesota, USA provided the opportunity to compare the effects of wildfire and timber harvesting in two peatland forest communities, nutrient-poor black spruce (*Picea mariana*) bogs (BSB) and nutrient-rich tamarack (*Larix laricina*) swamps (RTS). We found the response between the two communities and their corresponding vegetation to be highly sensitive to different types and severity of disturbance, ranging from modest shifts in ground layer vascular plants and bryophyte species abundance, to wholesale plant community transformation resulting from the removal of the upper peat surface. Fire had a positive influence on black spruce regeneration within BSB sites, particularly areas experiencing lower levels of fire severity, with seedling densities significantly higher than harvest and control areas. Our results also suggest that ecosystem recovery will be rapid after low-severity fire in these areas, given that localized areas of peat combustion created suitable microsites for black spruce seedling establishment ensuring this species will remain a component of the post-fire communities. In contrast, tamarack regeneration was only documented in harvested RTS sites. For BSB, there was spatial heterogeneity in peat consumption as a result of fire behavior interacting with varying moisture conditions throughout peat hummocks and hollows. Light to moderate burning created suitable black spruce seedbeds by reducing cover of *Sphagnum* moss and the dominant ericaceous shrub *Rhododendron groenlandicum*, and increasing the cover of pioneering mosses, such as *Polytrichum strictum*. In RTS sites, fire typically consumed the entire upper peat surface, resulting in homogenization of community composition and retrogression towards marsh-like conditions dominated by cattails (*Typha* spp.). These findings underscore the importance of accounting for post-fire microsite heterogeneity when developing silvicultural systems for emulating natural disturbance processes in conifer forests with a naturally accumulated surface peat layer. In addition, the state shifts observed in areas experiencing high severity fire suggest that increases in fire frequency and severity may create significant challenges to maintaining forested conditions in these areas, particularly in RTS.

1. Introduction

As the ecological importance of ground layer plant communities is increasingly acknowledged, the impacts of forest harvesting on these communities has received increased attention (Gilliam, 2007). Management approaches are also more commonly integrating aspects of natural disturbance regimes, such as disturbance frequency and severity, to satisfy ecologically-based objectives (Long, 2009). Yet, the response of the ground layer to a range of disturbances continues to be a challenging element to predict. Given the higher number of species and life-history strategies of ground layer plants relative to the overstory (Roberts, 2004; Gilliam, 2007), a better understanding of how harvests and natural disturbances affect ecosystem structure and composition is needed. Furthermore, these concepts are still in their infancy with regard to the extensive forested peatlands in North America, where deep peat and varying moisture conditions contribute to the complexity of predicting ground layer plant community response to disturbance.

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Stand-replacing wildfire, though rare, has been an important, historical disturbance influencing forest dynamics in boreal landscapes for millennia, with the Agassiz Lake Plain landscape shaped by many of these disturbances (Heinselman, 1968, 1970). However, due to fire suppression, disturbance regimes have shifted from wildfire to clearcutting as the primary disturbance (Pidgen and Mallik, 2013). Clearcutting-based regeneration methods are widely employed in many regions, including much of the managed area of the boreal peatlands (Locky and Bayley, 2007), where this approach has been suggested as a surrogate for stand-replacing fire events and for encouraging the regeneration of shade-intolerant tree species, such as tamarack (*Larix laricina* (Du Roi) K. Koch; Nyland, 2007). Yet, little is understood as to how post-disturbance recovery of the ground layer differs between clearcutting and stand-replacing disturbances, like fire, in these ecosystems. Despite similarities in levels of overstory disturbance between stand-replacing fires and clearcut harvests, i.e., significant tree mortality (or removal, in the case of harvest), there are also key differences, such as the amount of live and dead-tree legacies and the level of soil or peat disturbance (cf. Roberts, 2004). With wildfire, there may be considerable spatial differences in the residual peat layer resulting from moisture gradients in hummocks and hollows (Benscoter et al., 2005), but also the degree and depth of burning can be variable where fire can readily smolder for days in organic peat soils (Rein et al., 2008). These fire-induced effects in peatlands can also increase pH and nitrogen mineralization rates in more severely burned areas (Dyrness and Norum, 1983; McRae et al., 2001), whereas harvesting has less impact on nutrient cycling relative to wildfire, with logging largely removing macronutrients contained in tree biomass (Brumelis and Carleton, 1988; McRae et al., 2001; Roberts, 2004; Kemball et al., 2005). These important differences between natural and anthropogenic disturbances have the potential to generate diverging ecosystem responses, and thus post-disturbance patterns of vegetation recovery, including both vascular and nonvascular plants (Roberts, 2004; McRae et al., 2001; Franklin et al., 2007; Johnstone et al., 2010; Fenton et al., 2013; Pidgen and Mallik, 2013).

Examining the influence of disturbance processes on the presence of ericaceous shrubs is also an important consideration in peatland communities, because these shrubs are known to impact tree regeneration through allelochemical reactions and nutrient competition (Mallik, 1995; Inderjit and Mallik, 1996; Mallik, 2003). Ericaceous shrubs, particularly Labrador tea (*Rhododendron groenlandicum* [Oeder] Kron & Judd), can regenerate vigorously from belowground root rhizomes post-disturbance (Viereck and Johnson, 1990; Mallik, 2003). Given the comparatively low levels of ground layer disturbance associated with harvesting relative to wildfire, post-harvest areas generally lack the suitable seedbeds for conifer regeneration that fire creates, i.e., reduced peat microtopography and ericaceous competition (Mallik, 2003; Hébert et al., 2010; Lafleur et al., 2011), with several studies documenting increases in ericaceous cover following harvesting in black spruce (*Picea mariana* (Mill.) Britton, Sterns & Poggenb) communities (Groot 1996; Dussart and Payette 2002).

To compare post-disturbance plant community and regeneration patterns between fire and harvest, this study takes advantage of a rare wildfire event that occurred following severe drought conditions in September of 2012 in northern Minnesota, USA. The North Minnie fire burned over 10,000 ha and resulted in a range of fire severities across a mosaic of peatland communities providing a unique opportunity to increase our understanding on wildfire in lowland conifer peatlands. This region represents the southernmost extent for boreal peatlands in North America and is uniquely situated to examine the impacts of wildfire and forest harvesting as these ecosystems are projected to be significantly impacted by changes in future climate and altered disturbance regimes (Kasischke and Turetsky, 2006; Galatowitsch et al., 2009; Brown and Johnstone, 2012; Moritz et al., 2012).

The overall objective of this study was to quantify differences in seedling regeneration associated with post-disturbance seedbed condition, as well as ground layer plant community composition, two growing seasons after wildfire and clearcut harvesting disturbances in two forested peatland types. Many of the vascular and nonvascular species compositional differences following these two disturbance types are related to differences in ground layer disturbance associated with microsite conditions. By relating early vegetation development observed following wildfires and clearcut harvesting to the level of disturbance, we sought to address the following questions: (1) how does disturbance severity, as well as type, affect early regeneration success of conifer seedlings in nutrient-rich tamarack swamps and nutrient-poor, black spruce bogs; (2) how does disturbance type affect composition of ground layer vascular and nonvascular plant species in these systems, and (3) how does vegetation response to disturbance vary between tamarack swamps and black spruce bogs?

2. Methods

2.1. Study area

The study area is located primarily in the Red Lake Wildlife Management Area (WMA) in Beltrami and Lake of the Woods counties, Minnesota, USA (Fig. 1). A few harvested sites were also located in the neighboring Beltrami and Pine Island State Forests, as the WMA had a limited number of recent clearcuts that met our criteria, thus requiring us to expand our search. This entire region was formerly occupied by Glacial Lake Agassiz and is characterized by flat (topographic relief is less than 15 m), poorly drained soils of lacustrine origin that have developed through paludification into the most extensive boreal peatlands in the lower United States (Glaser, 1987).

The climate for this region is characterized as mid-continental, where annual precipitation is substantially more than evaporation with the water table at or close to the surface, thus inhibiting decomposition of plant material. Mean annual precipitation for the region is 66 cm, with approximately 70% occurring during the growing season. In 2012, the year of the North Minnie Fire, annual precipitation for the region prior to the fire (Oct. 2011–Sept. 2012) was approximately 41 cm below average (Minnesota Climatology Working Group; http://climate.umn.edu). The growing season is short, generally 98–111 days. The normal mean temperatures for summer months (June-August) range from 15 to 20 °C with winter months averaging −20 to −7 °C (NOAA Climate Monitoring for 1971–2015; http://ncdc.noaa.gov/cag/time-series).

This study focused on two forested peatland communities: nutrient-poor black spruce bogs (BSB), and nutrient-rich tamarack swamps (RTS). Black spruce-dominated bogs in the study area occur on deep peat (>1 m), which isolates the plant rooting zone from the underlying mineral-rich groundwater. Surface water is typically acidic (pH < 4.2), with nutrient inputs supplied primarily by atmospheric precipitation, limiting species diversity to a small subset adapted to tolerate these conditions. Tamarack swamps also occur on well-developed peat, although less so (typically over 40 cm) than bogs. These communities are influenced by mineral-rich groundwater (pH 5.5–7), thus species diversity is much higher than in black spruce bogs. These communities were selected because they represent the two plant communities most affected by the North Minnie wildfire and they are commonly managed for forest products.