

Research papers

Post-fire ecohydrological conditions at peatland margins in different hydrogeological settings of the Boreal Plain



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ABSTRACT

In the Boreal Plain of Canada, the margins of peatland ecosystems that regulate solute and nutrient fluxes between peatlands and adjacent mineral uplands are prone to deep peat burning. Whether post-fire carbon accumulation is able to offset large carbon losses associated with the deep burning at peatland margins is unknown. For this reason, we examined how post-fire hydrological conditions (*i.e.* water table depth and periodicity, soil tension, and surface moisture content) and depth of burn were associated with moss recolonization at the peatland margins of three sites. We then interpreted these findings using a hydrogeological systems approach, given the importance of groundwater in determining conditions in the soil-plant-atmosphere continuum in peatlands. Peatland margins dominated by local groundwater flow from adjacent peatland middles were characterized by dynamic hydrological conditions that, when coupled with lowered peatland margin surface elevations due to deep burning, produced two common hydrological states: 1) flooding during wet periods and 2) rapid water table declines during dry periods. These dynamic hydrological states were unfavorable to peatland moss recolonization and bryophytes typical of post-fire recovery in mineral uplands became established. In contrast, at a peatland margin where post-fire hydrological conditions were moderated by larger-scale groundwater flow, flooding and rapid water table declines were infrequent and, subsequently, greater peatland-dwelling moss recolonization was observed. We argue that peatland margins poorly connected to larger-scale groundwater flow are not only prone to deep burning but also lags in post-fire moss recovery. Consequently, an associated reduction in post-fire peat accumulation may occur and negatively affect the net carbon sink status and ecohydrological and biogeochemical function of these peatlands.

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1. Introduction

Peatland ecosystems are wetlands characterized by thick organic deposits (NWWG, 1997) and have the highest carbon density per unit area of any ecosystem in the boreal biome (Bradshaw and Warkentin, 2015). Wildfire is the largest disturbance in spatial extent affecting peatlands ecosystems and, in sub-humid regions of the boreal forest, occurs as frequently in peatlands as in mineral uplands at 100 to 120 year intervals (Turetsky et al., 2004). Peatlands are generally resilient to typical (low) burn severity wildfires

(depth of burn (DOB) = 0.05–0.10 m) (Benscoter and Wieder, 2003; Shetler et al., 2008) and return to a net carbon sink status ~20 years after wildfire (Wieder et al., 2009). However, deep burning (>0.20 m) has recently been observed at peatland margins in some hydrogeological settings of Alberta's Boreal Plain (Hokanson et al., 2016; Lukenbach et al., 2015b). Given that upland-peatland margins are important zones for biogeochemical transformations in this landscape (Dimitrov et al., 2014a; Hartshorn et al., 2003), potential shifts in ecohydrological and biogeochemical function due to deep burning are a concern (Lukenbach et al., 2015b; Kettridge et al., 2015).

The short and long-term effects of wildfire will, in part, be controlled by whether the rate of post-fire carbon accumulation is able to offset large carbon losses associated with deep burning. In

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peatland ecosystems, the rate and pattern characterizing the recolonization of peat-forming vegetation (e.g. *Sphagnum*, *Carex*) is critical for post-fire carbon (re-) accumulation and, by extension, the maintenance of ecosystem structure and function (e.g. Rydin et al., 2013). As such, the aim of this paper was to examine how both hydrogeological setting and deep burning affect post-fire hydrological conditions at peatland margins and how these hydrological conditions relate to patterns of post-fire moss recolonization.

A peatland's interaction with different scales of groundwater flow has a large control on peatland water table (WT) positions and ecohydrological conditions (Aldous et al., 2015; Godwin et al., 2002; Winter, 1999). To minimize terminological confusion, we refer to this influence of groundwater based on the degree of connection between a peatland margin and larger-scale groundwater flow (c.f. Winter and LaBaugh, 2003). We provide a hypothetical conceptualization illustrating how connection to larger-scale groundwater flow influences WT positions along upland-peatland interfaces (Fig. 1). Peatland margins poorly connected to larger-scale groundwater flow systems exhibit dynamic WT positions because water fluxes are dominated by atmospheric exchanges or localized groundwater flow to and from adjacent peatland middles (Ferone and Devito, 2004; Thompson et al., 2015). Rapid responses to near-term climatic conditions, in conjunction with the sub-humid climate of the Boreal Plain, result in rapid and deep (>1 m) WT drawdowns at peatland margins during drought (Ferone and Devito, 2004; Thompson et al., 2015). Such WT drawdowns subject the dense peat within margins to low moisture contents that, when coinciding with wildfire, results in the frequent occurrence of deep burning (Fig. 1) (Lukenbach et al., 2015b). Although these margins are a relatively small proportion (<10%) of the total area of a peatland, deep burning can account for as much as 50 to 90% of the total carbon loss, even in larger (>50 ha) peatlands (Hokanson et al., 2016).

The groundwater-soil-plant-atmosphere continuum (c.f. Gou and Miller, 2014) in peatlands is characterized by strong linkages between groundwater and the atmosphere through vadose zone processes (Dettmann and Bechtold, 2016; Thompson and Waddington, 2013b). Our conceptual model demonstrates how shallow and deep WTs influence volumetric moisture content (θ) and soil tension (Ψ) in peat depth profiles (Fig. 1) (Thompson and Waddington, 2008). When WTs are shallow, depth to WT- Ψ relationships often exhibit linear, close to 1:1 relationships (Lukenbach et al., 2015a, 2016), indicating that water losses due to evaporation are rapidly replenished by upflux from the WT (Lukenbach et al., 2015a). Alternatively, during large WT drawdowns (>0.70 m), this relationship becomes non-linear and near-surface Ψ rises appreciably (Lukenbach et al., 2015a; Lindholm and Markkula, 1984), resulting in water stress on peatland vegetation (Thompson and Waddington, 2008). These interactions helped explain slow post-fire moss recolonization in the middles of peatlands poorly connected to larger-scale groundwater flow systems, as these sites had more frequent and greater WT drawdowns (Lukenbach et al., 2015a). Given the role of hydrogeological setting in determining where peatland margins underwent deep burning (i.e. Fig. 1a), it is likely that these same locations are also prone to low post-fire WT positions during dry periods and, accordingly, should exhibit a time-lag and/or different trajectory of recovery in post-fire vegetation recolonization.

Deep burning at peatland margins may also interact with the scale and/or type of groundwater flow influencing a peatland. Large organic soil losses at peatland margins may alter water and solute transfer between peatlands and adjacent mineral upland ecosystems. Moreover, deep burning potentially increases flooding frequency by lowering the elevation of the peat surface (Thompson and Waddington, 2013a) and increasing the duration of inundation. While dry conditions are known to limit peatland moss recolonization (Thompson and Waddington, 2008), flooding may limit the ability of peatland vegetation to recolonize margin areas

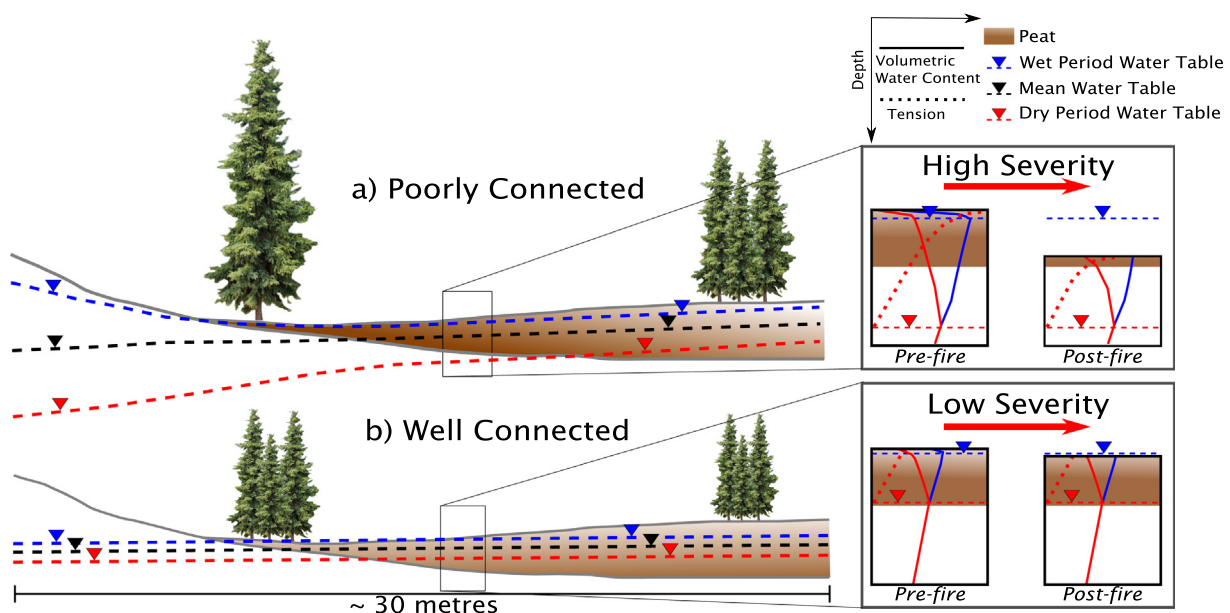


Fig. 1. Hypothetical conceptual model of the groundwater-soil-plant-atmosphere continuum along upland-peatland transition zones in two disparate hydrogeological settings a) a site poorly connected to larger-scale groundwater flow and b) a site well connected to larger-scale groundwater flow. Dashed red, black, and blue lines indicate water table configurations during wet, mean, and dry conditions, respectively. Faint boxes on the cross sections correspond to the location of peat margin soil profiles shown on the right side of the figure. Soil profiles show pre and post-fire tension profiles (dotted lines), volumetric water content profiles (solid lines), and water tables (dashed lines) under dry (red) and wet (blue) conditions with the likely burn scenarios (high versus low severity) influencing post-fire conditions. Under saturated conditions, tension profiles are not shown. In both the cross sections and profiles, the peat color gradient represents differences in bulk density (darker = denser). Trees are scaled according to their anticipated size under the different water table depths. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

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