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Burned and unburned peat water repellency: Implications for peatland evaporation following wildfire

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SUMMARY

Water repellency alters soil hydrology after periods of wildfire, potentially modifying the ecosystem recovery to such disturbance. Despite this potential importance, the extent and severity of water repellency within burned peatlands and its importance in regulating peatland recovery to wildfire disturbance remains poorly understood. We characterised the water repellency of peat in a burned (one year post-fire) and unburned peatland in the Western Boreal Plain utilising the water drop penetration time and ethanol droplet molarity tests. Burned *Sphagnum* moss and feather moss sites had a more severe degree of water repellency than unburned sites, with differences being more pronounced between burned and unburned feather moss sites. Burned feather moss exhibited the most extreme water repellency, followed by unburned feather moss, and burned *Sphagnum*. The severity of water repellency varied with depth through the near surface of the moss/peat profile. This was most evident within the burned feathermoss where more extreme water repellency was observed at the near-surface compared to the surface, with the most extreme water repellency found at 1 and 5 cm depths. Unburned *Sphagnum* was completely hydrophilic at all depths. We suggest that the extreme water repellency in near-surface feather moss peat acts as a barrier that impedes the supply of water to the surface that replaces that lost via evaporation. This leads to drying of the near-surface vadose zone within feather moss areas and a concomitantly large decrease in peatland evaporation within feather moss dominated peatlands. This negative feedback mechanism likely enhances the resilience of such peatland to wildfire disturbance, maintaining a high water table position, thereby limiting peat decomposition. In comparison, such a feedback is not observed strongly within *Sphagnum*, leaving *Sphagnum* dominated peatlands potentially vulnerable to low water table positions post disturbance.

1. Introduction

Northern peatlands represent a globally significant carbon stock (Turunen et al., 2002) and contain approximately one-third of all global soil carbon. However, there is concern that this carbon stock may be vulnerable under future climatic conditions (Ise et al., 2008; Turetsky et al., 2011) as the severity and frequency of drought (Roulet et al., 1992; Petrone et al., 2005) and wildfire (Moritz et al., 2012; Flannigan et al., 2013) are both expected to increase. Evapotranspiration often provides the primary pathway for water loss from peatlands (Lafleur et al., 2005; Devito et al., 2005; Petrone et al., 2007; Brown et al., 2010). Therefore, negative feedbacks that regulate evapotranspiration (Kellner, 2001; Kettridge et al., 2013) are critical for maintaining the near saturated hydrological conditions that characterise peatlands (Ingram, 1978; Holden, 2005) and for providing ecosystems resilient to such disturbance, especially in the sub humid climates of the Western Boreal Plain (Devito et al., 2005; Petrone et al., 2007).

Peatland evapotranspiration can approximately equal potential evapotranspiration (Rouse, 1998; Lafleur et al., 2005) under near-saturated conditions, and in some cases can even exceed it where landscape configurations and high atmospheric demand can enhance the turbulent transfer of water vapour (Petrone et al., 2007). However, large surface temperature increases (up to 30 °C) have been observed on some burned peat (Kettridge et al.,

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2012) that were attributed to a strong decrease in peatland evaporation (Kettridge and Waddington, 2013) owing to a drier vadose zone following wildfire (Thompson and Waddington, 2013). While more research is needed to quantify the prevalence of this change in evaporation, it represents a potentially strong negative feedback post-fire that retains moisture within the peat after a period of disturbance. This negative feedback likely maintains high water-table positions, limiting peat decomposition and enabling the re-establishment of moss species. The exact mechanism controlling this reduction in near-surface peat moisture content and the associated reduction in evaporation is unclear and requires further attention.

One possible mechanism controlling this observed reduction in surface evaporation in peatlands after wildfire is the development of water repellent peat. Slightly water repellent peat has been observed in post-wildfire organic soils in Alaska (O'Donnell et al., 2009) suggesting the development of a water repellent layer in near-surface peat post-fire (Beatty and Smith, 2013). High soil temperatures during wildfire induce bonding of organic substances to soil particles, leading to water repellency in previously hydrophilic soils (Doerr et al., 2000). During wildfire, volatized organic substances can move down the soil profile to cooler temperatures where they condense and coalesce onto soil particles creating water repellent layers deeper in the profile (Debano, 2000). Moreover, soils also become water repellent following drying (Doerr et al., 2000). Such drying may result from evaporation under the extreme temperatures of the wildfire event or the modified hydrological conditions post disturbance (Thompson et al., 2013). These water-repellent surfaces cause water droplets to bead on the surface rather than infiltrating into the soil profile (Dekker et al., 2000). As such, burned organic matter has complex and highly variable wettability at multiple spatial, as well as temporal scales. Water repellency has been shown to persist within soils for a period of months to years (Debano, 2000; Doerr et al., 2000). However, little is known about the longevity of soil water repellency and the different processes that control its breakdown over time (Doerr et al., 2000).

There is an immediate need to characterise the temporal and spatial variability in peat water repellency. The aim of this study is to undertake the first comprehensive characterisation of peat water repellency of recently burned and unburned *Sphagnum* and feather moss communities. We hypothesize that (1) burned peat would be more water repellent than unburned peat, and (2) that this water repellency will occur at depth. Moreover, based on the findings of O'Donnell et al. (2009) we also hypothesize that (3) burned peat of *Sphagnum* botanical origin will be more water repellent than burned peat of feather moss origin.

2. Methodology

2.1. Study area and research design

Measurements were conducted at two study sites within a wetland complex within the Utikuma Lake Region Study Area (URSA) in north-central Alberta (56.107°N 115.561°W). The two study sites represent two lobes (~200 m apart) on the edge of a larger wetland complex located on a coarse-textured outwash plain; see Smerdon et al. (2005) for details of the wider study area and its associated hydrology. Study site 1, referred to as 'burned' from this point forwards and represents a small lobe approximately 60 m by 150 m in size surrounded by aspen forestland (cf. Devito et al., 2012). Prior to the fire, the burned peatland was characterised by feather moss lawns, *Sphagnum fuscum* hummocks and a vascular vegetation cover of *Rhododendron groenlandicum* and *Rubus chamaemorus* (vegetation determined from the assessment of post-fire vegetation and similar adjacent unburned peatlands). A dense black spruce tree canopy with a stem density of approximately 7000 stems per hectare was evident across the study sites prior to fire. The peatland was burnt in May of 2011 as part of the ~90,000 ha Utikuma Complex forest fire (SWF-060). The fire resulted in the 100% mortality of the above ground biomass. Despite the high intensity of the crown fire there was no combustion to any significant depth of the *Sphagnum* moss communities within the majority of the central proportion of the peatland in which this study was conducted. Within *Sphagnum* areas, this was determined through the inspection of capitula at the moss surface; *Sphagnum* capitula and leaves remained intact. The precise depth of combustion within feather moss was more difficult to quantify with certainty due to the less defined structure of unburned species. Further, combustion of the feather moss was more severe, with the combustion of the feather moss leaves at the surface. However, a comparison of measurement locations to points of no combustion (adjacent to *Sphagnum* stems or black spruce trees without exposed adventitious roots), showed no reduction in the surface elevation as a result of wildfire. Study site 2 is referred to as 'unburned' from this point forward. The unburned peatland represent a second lobe of the larger wetland complex. Comparable to the burned peatland, the unburned peatland is characterised by feather moss lawns and *S. fuscum* hummocks and a canopy of black spruce and tamarack (5000 stems per ha). The unburned peatland (last burned ~140 years ago; M. Turetsky, personal communication, 2013) is considered to provide a good approximation of the pre fire vegetation communities within the burned study site.

To examine peat water repellency, five experimental plots were established within each of the four surface types: burned feather moss, burned *Sphagnum*, unburned feather moss, and unburned *Sphagnum*. The plots were established in mid August 2012, 15 months after the fire. This measurement time aimed to provide a snapshot of peatland water repellency at a time post fire when water repellency is predicted to endure based on research conducted within other environments. To examine peat water repellency within each plot, 10 replicate measurements of the water drop penetration test (WDPT) and molarity of an ethanol droplet (MED) test were made in situ at the peat surface and at a depth of 2 and 5 cm (near-surface). Details of the WDPT and MED tests are presented below. In addition, because of the more extreme water repellency observed within the burned feather moss plots, a more intensive study was undertaken at each of these plots. Ten replicates of WDPT and MED tests were performed in situ at 1 cm depth increments at each feather moss plot from the peat surface to a depth of 10 cm. These measurements provide a snap shot of the water repellency at a single point in time post fire.

2.2. Water drop penetration time test

The water drop penetration time (WDPT) test measures the persistence of water repellency of an exposed soil surface. Briefly, the WDPT test involves measuring the time taken for a water droplet placed on the surface to infiltrate completely. The longer the time taken for the water to infiltrate, the greater the persistence of soil water repellency. Water droplets were applied to the measurement surface with a pipette (average drop volume 0.056 ml ± 0.003 ml SE). The penetration time of each water drop was recorded to the nearest second. However, in order to maximise the number of measurements, water droplets were timed for a maximum of 12 min within this study. The impact of this maximum limit on the calculated mean water drop penetration times should be bourne in mind in the subsequent analysis. The water repellency was evaluated using the Dekker et al. (2000) WDPT water repellency classification scheme, classifying the soil as