Journal of Hydrology 554 (2017) 656–665

Contents lists available at ScienceDirect

Journal of Hydrology

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

Research papers

# Peatland water repellency: Importance of soil water content, moss species, and burn severity

P.A. Moore [a,*], M.C. Lukenbach [a,b], N. Kettridge [c], R.M. Petrone [d], K.J. Devito [e], J.M. Waddington [a]

[a] School of Geography and Earth Sciences, McMaster University, 1280 Main Street West, Hamilton, Ontario L8S 4K1, Canada
[b] Department of Earth and Atmospheric Sciences, University of Alberta, Edmonton, AB T6G 2E3, Canada
[c] School of Geography, Earth and Environmental Sciences, University of Birmingham, Edgbaston, Birmingham B15 2TT, UK
[d] Department of Geography and Environmental Management, University of Waterloo, Waterloo, ON N2L 3C5, Canada
[e] Department of Biological Sciences, University of Alberta, Edmonton, AB T6G 2E3, Canada

ARTICLE INFO

*Article history:*
Received 1 August 2017
Received in revised form 9 September 2017
Accepted 19 September 2017
Available online 20 September 2017
This manuscript was handled by G. Syme, Editor-in-Chief

*Keywords:*
Water repellency
Moss
*Sphagnum*
Feathermoss
Wildfire
Peatland

ABSTRACT

Wildfire is the largest disturbance affecting peatlands, with northern peat reserves expected to become more vulnerable to wildfire as climate change enhances the length and severity of the fire season. Recent research suggests that high water table positions after wildfire are critical to limit atmospheric carbon losses and enable the re-establishment of keystone peatland mosses (*i.e. Sphagnum*). Post-fire recovery of the moss surface in *Sphagnum*-feathermoss peatlands, however, has been shown to be limited where moss type and burn severity interact to result in a water repellent surface. While in situ measurements of moss water repellency in peatlands have been shown to be greater for feathermoss in both a burned and unburned state in comparison to *Sphagnum* moss, it is difficult to separate the effect of water content from species. Consequently, we carried out a laboratory based drying experiment where we compared the water repellency of two dominant peatland moss species, *Sphagnum* and feathermoss, for several burn severity classes including unburned samples. The results suggest that water repellency in moss is primarily controlled by water content, where a sharp threshold exists at gravimetric water contents (GWC) lower than ~1.4 g g$^{-1}$. While GWC is shown to be a strong predictor of water repellency, the effect is enhanced by burning. Based on soil water retention curves, we suggest that it is highly unlikely that *Sphagnum* will exhibit strong hydrophobic conditions under field conditions.



## 1. Introduction

Peatlands are wetlands defined, in part, by thick accumulations of organic matter (>0.4 m in Canada, National Wetlands Working Group, 1997). While representing less than 3% of global land area, northern peatlands comprise roughly one-third of global soil carbon storage (Yu et al., 2010). Fire-prone peatland-dominated regions exist over large areas of western boreal Canada and Siberia (de Groot et al., 2013), where relatively short fire return intervals play an important role for carbon storage and vegetation dynamics (Weber and Flannigan, 1997). Moreover, in western continental Canada, peatlands in a sub-humid climate exist at the limit of their climatic tolerance (Vitt et al., 2000). The contemporary carbon storage rate for peatlands in this region is estimated at 19.4 g C m$^{-2}$ y$^{-1}$ (Vitt et al., 2000), but fires have the potential to release a large amount of the long-term carbon stored in these ecosystems (Hokanson et al., 2016) and reduce carbon accumulation rates for years to decades (Turetsky et al., 2002). With an increase in large fires and total burned area for boreal peatlands (Kasischke and Turetsky, 2006; Turetsky et al., 2011), the carbon storage function of boreal peatlands may further be degraded. As such, there is concern that the predicted increase in climate change mediated disturbances, such as wildfire and/or drought, will negatively impact the contemporary carbon storage potential of these peatlands (Vitt et al., 2000; Flannigan et al., 2000; Flannigan et al., 2005).

However, peatlands which are not significantly affected by anthropogenic disturbance are considered resilient ecosystems, owing to a number of negative ecohydrological feedbacks (Waddington et al., 2015). Following wildfire, water repellency has recently been suggested to be a potentially important negative feedback acting to conserve water, and potentially aid in vegetation recovery (Kettridge et al., 2017), and is prevalent in post-fire Boreal Plains bogs (Kettridge et al., 2014; MacKinnon, 2016). Whilst well studied in mineral soils (*cf.* Doerr et al., 2000), few

* Corresponding author.
*E-mail address:* paul.moore82@gmail.com (P.A. Moore).

https://doi.org/10.1016/j.jhydrol.2017.09.036
0022-1694/© 2017 Elsevier B.V. All rights reserved.

studies have examined water repellency in peatland ecosystems, where the soil surface is typically comprised of living mosses (O'Donnell et al., 2009b; Kettridge et al., 2014). Water repellency has been shown to affect capillary forces driving water movement in porous media (Shokri et al., 2009), limiting capillary flow to the evaporating surface from wetter and/or saturated soil layers (Diamantopoulos et al., 2013), thus potentially reducing surface evaporation (Shahidzadeh-Bonn et al., 2007). Therefore, water repellency may constitute an important ecohydrological feedback in peatlands, whereby evaporation is severely limited (Kettridge et al., 2017), amplifying the water table depth – moss resistance feedback (see Waddington et al., 2015), and thus conserving water.

While fire may induce or enhance soil water repellency (*cf.* DeBano, 2000), the degree of soil water repellency has also been linked to soil carbon (Karunarathna et al., 2010) and water content (Fishkis et al., 2015). In general, the soil characteristics, moisture content, and temperature of combustion in organic soil layers will all affect the production of hydrophobic compounds at depth (Doerr et al., 2000). In the case of peatlands which tend to have very high carbon content in near-surface soils (*e.g.* Yu, 2012) and where smouldering (*i.e.* low temperature) tends to dominate over flaming combustion on the peat surface during wildfire (*e.g.* Rein et al., 2008), there is likely a relatively high potential for the production of hydrophobic compounds as a result of wildfire (*e.g.* Neff et al., 2005).

Post-fire near-surface water repellency in peatlands can be created or exacerbated based on botanical origin and depth (O'Donnell et al., 2009b; Kettridge et al., 2014) and is persistent for several years (*e.g.* Kettridge et al., 2014; MacKinnon, 2016). As such, it is necessary to consider the importance of water repellency in relation to both peatland vadose zone hydrology and moss recovery post-fire. However, past studies on peatland water repellency persistence are somewhat contradictory. O'Donnell et al. (2009b) found minimal persistence of hydrophobicity 24 months post-fire at the peat surface for both *Sphagnum* and feathermoss species. In contrast, two studies undertaken in northern Alberta 15 months and 38 months post-fire showed significant and persistent near-surface water repellency for both feathermoss and *Sphagnum* species (Kettridge et al., 2014; MacKinnon, 2016). Both burned and unburned feathermoss species have been shown to exhibit relatively strong water repellency in the field; however, the degree of water repellency was shown to be greater for the burned feathermosses (Kettridge et al., 2014; MacKinnon, 2016). Comparatively, *Sphagnum* has been shown to exhibit only slight water repellency in burned locations and essentially none in unburned locations (Kettridge et al., 2014). It is possible that these observed differences of in situ water repellency are due to differences in water content, given that water repellency in mineral soils has been previously linked to water content (Fishkis et al., 2015). Moreover, it has been suggested that desiccation of peat can exacerbate any water repellency that may be present (Valat et al., 1991); however, no study to our knowledge has examined the effect of water content on the water repellency of moss/peat soils. Examining the influence of water content on peat water repellency, especially in the post-fire environment, is essential not only to understand the temporal variability of water repellency but also water repellency persistence. While studies in mineral soils have found that post-fire water repellency can break down during wetting events (*e.g.* MacDonald and Huffman, 2004), it remains unknown if peatland wetting events (rainfall and/or an increase in water table position), lead to a decline in the spatial extent or severity of water repellency.

To address this critical knowledge gap, we sought to determine: 1) whether there were significant interactive effects of water content with burn status and species on the degree of water repellency in peatland moss/soil samples; 2) whether prolonged saturation decreased the degree of water repellency of burned feathermoss peat; and 3) whether moisture retention characteristics of burned and unburned feathermoss and *Sphagnum* peat varied significantly and thus infer how differences in moisture retention might manifest under in situ conditions. For the first objective, we hypothesized that the effect of low moisture content, feathermoss species, and burning on near-surface peat water repellency was additive and that this combination would exhibit the greatest degree of water repellency. For the second objective, we hypothesized that prolonged saturation would lead to a decrease in the severity of water repellency.

## 2. Methods

### 2.1. Study area and water repellency sampling

*Sphagnum* (*Sphagnum fuscum*) and feathermoss (*Pleurozium schreberi*) samples were collected in July of 2013 from a mature treed bog in the Utikuma Lake Research Study Area (56.107°N, 115.561°W) (Devito et al., 2012) that was partially burned in May of 2011. The burned and unburned portions are located ~100 m apart and are approximately 100 × 150 m and 90 × 150 m in size, respectively. Both portions of the bog are characterized by feathermoss (>95% *Pleurozium schreberi*) hollows, *S. fuscum* hummocks, vascular vegetation cover of *Rhododendron groenlandicum* and *Rubus chamaemorus*, and a dense black spruce (*Picea mariana*) tree canopy. For more details of the local hydrology, see Smerdon et al. (2005) and Lukenbach et al. (2017).

Small moss and peat blocks roughly 0.15 × 0.15 × 0.05 m were taken from both burned and unburned areas at three depths spanning 0–0.05 m, 0.03–0.08 m, and 0.06–0.11 m. Target depths of 0, 0.03, and 0.06 m were chosen to reflect changes in water repellency observed in the near- surface in other studies (*i.e.* Kettridge et al., 2014). A sample thickness of 0.05 m was chosen so that moss/peat structure could be maintained while having a thin sample which could dry in a relatively uniform manner. Treatments comprising both burn severity and species were defined similar to Lukenbach et al. (2015). There were five treatments consisting of burned and unburned *Sphagnum fuscum* (hereafter *B.Sph* and *Sph*, respectively), burned and unburned feathermoss (hereafter *B.FM* and *FM*, respectively), and burned hollows (*B.Hol*). *B.Hol* generally corresponds with higher burn severity where we were unable to determine the pre-fire moss cover. *B.Sph* corresponds with light burn severity where *Sphagnum* capitula are singed but have not been fully consumed by combustion. For our first research objective, ten samples were collected for each of the five treatments ($n = 50$). For our second research objective, 50 samples of burned feathermoss were collected in order to test whether saturation (see Section 2.2) had a significant effect on the persistence of water repellency. A larger sample size was chosen for the second objective because there has been no previous research that we are aware of on which to make an *a priori* assumption of effect size. We focused on feathermoss only for the second lab experiment because field-based measurements of Kettridge et al. (2014), as well as initial results from the first laboratory experiment had shown that water repellency in burned feathermoss was high, while that for burned *Sphagnum* was comparatively quite low.

### 2.2. Water drop penetration time

Water drop penetration time (WDPT) tests were undertaken on intact samples in the laboratory every 24 h. Distilled water was dispensed using a pipette held just above the peat sample surface and 10 equally sized water drops applied (Fig. 1). The WDPT was measured upon contact until the complete infiltration of the drop