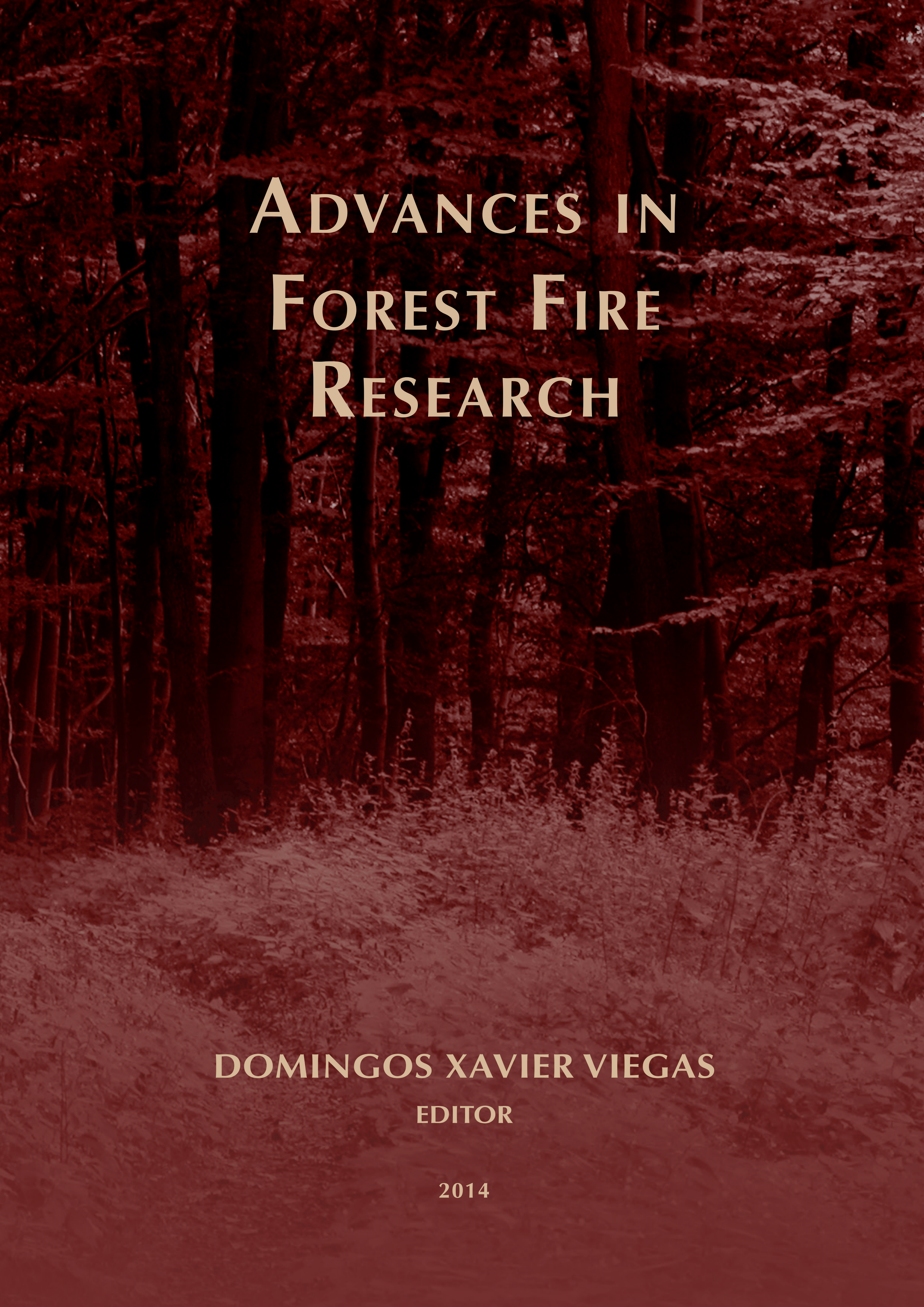

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Fuel and climate controls on peatland fire severity

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Abstract
A series of experimental fires were conducted to investigate the effect of ground-fuel structure and fuel moisture content in controlling fire severity in a *Calluna vulgaris* dominated environment. Their influence on fire-induced temperature pulses into the soil (peat) was quantified. The effect of fire-related changes in fuel structure on peat microclimate was also examined. We found the moss and litter (M/L) layer to be important in insulating peat from fire-induced temperature pulses, especially at the peat surface. We recorded higher fire-induced peat temperatures and residence times in microplots where a drought had been simulated, with climatic conditions playing a key role. The removal of the heather canopy due to burning and the change in structure of the M/L layer were found to similarly increase both peat daily temperature fluctuation and peat mean temperature.

Keywords*: Calluna vulgaris, drought, fire severity, FMC, litter, moss, peat*

1. Introduction

Peatlands in high-latitude regions represent a large soil carbon reservoir, and their degradation could have important implications for the climate – ecosystem feedback governed by the carbon cycle (Heimann & Reichstein 2008). As summer droughts in northern regions are projected to intensify due to climate change (IPCC 2013), thus laying the foundations for more severe fires, it is necessary to understand the key mechanisms controlling fire effects on peatlands.
Peat deposits in the U.K. are usually covered by a mixture of mosses and dead shrub foliage a few cm deep. The moisture content of these ground fuel layers respond quickly to weather conditions. The M/L layer is thought to be important in insulating peat from temperature pulses, and possibly ignition, during the passage of a flaming fire-front. The structure of the M/L layer may therefore be a critical factor in keeping fire severity low despite high fire intensity. Drought conditions may lower the moisture content of the M/L layer below its flammability threshold (Davies and Legg 2010), leading to a step change in fire behaviour and fire severity that threatens carbon stores through peat combustion, altered soil respiration or post-fire degradation. We currently have no quantitative evidence demonstrating the extent to which peat is heated or scorched during burning and how the M/L layer mitigates the effects of the fire, both in terms of temperature penetration during burning and post-fire peat microclimate.
We hypothesise that the M/L layer is a key mechanism in controlling fire behaviour and fire severity. To investigate this we conducted a series of experimental fires in Glen Tanar (Aberdeenshire, Scotland, UK), in a heather (*Calluna vulgaris* (L.) Hull) dominated moorland where prescribed burning has traditionally been used to improve habitat for red grouse (*Lagopus lagopus scoticus*), and in Braehead Moss (South Lanarkshire, Scotland), a Special Site of Scientific Interest (SSSI) designated raised bog.

2. Methods

2.1. Ground fuel structure and below-ground temperature penetration

To examine the role of the M/L layer in temperature penetration a series of experimental fires were completed where the M/L layer was manipulated. The M/L layer was either left untouched, removed after the fire, or removed before the fire in 1 x 1 m microplots. Control microplots where set up outside the fire area. This allowed us to separate the relative importance for peat microclimate of the M/L layer, the heather canopy and scorching of the peat surface during the fire. A total of seven experimental fires ignited as head fires were completed in Glen Tanar, with two replicate microplots of each treatment per fire. To study temperature penetration during the fire, two Hobo™ loggers connected to a K-type twisted pair thermocouple were buried at the peat surface and two cm below in each microplot. The loggers were retrieved after 35 min of the start of the fire. As for changes in peat microclimate, long-term peat temperature were recorded two cm below the top of the peat in one microplot per treatment in each fire using an iButton™ temperature logger (0.5°C accuracy, 2h logging interval). Peat microclimate was recorded from April 2013 to April 2014.

2.2. The effect of drought on ground fuel moisture content, flammability and fire severity

To investigate the extent to which M/L layer moisture content and flammability controls variation in fire severity, summer drought was simulated in 2 m x 2 m microplots using rain-out shelters (Figure 1). Ten experimental fires were completed in Glen Tanar and another ten in Braehead Moss between September 2013 and September 2014. Each fire comprised two drought-treated microplots and two untreated microplots. Measurements included: fuel load and structure assessment following the FuelRule method (Davies *et al*. 2008), pre-fire peat, M/L layer, live heather and dead heather fuel moisture content (FMC), moss depth above the thermocouple, fire-induced below-ground temperature pulses, weather conditions and moss consumption.

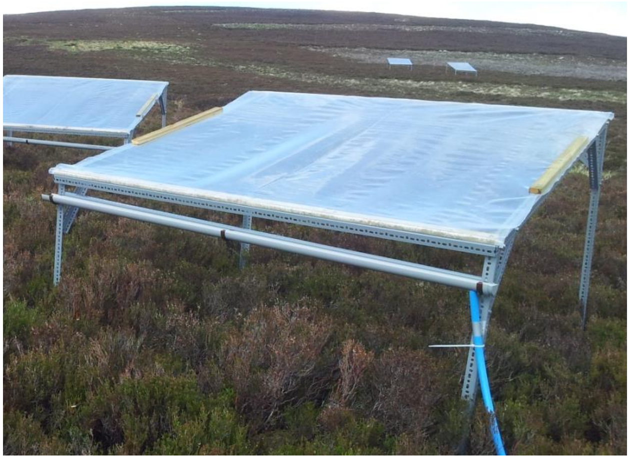

Figure 1. Rain-out shelter (left) and post-fire ground fuel smouldering limited to treated microplots (right)

3. Results

3.1. Ground fuel structure and below-ground temperature penetration

A substantial increase in peat temperature residence (in °C s) was observed at the peat surface in microplots where the M/L layer had been removed: microplots where the M/L layer hadn't been removed presented an average 7800 °C s (SD = 7000, n = 28) while microplots where the M/L layer had been removed had an average temperature residence of 19000 °C s (SD = 11100, n = 14). Effects

2 cm below the top of the peat were less evident although still substantial (Figure 2). Average temperature residence values were 1900 °C s (SD = 2300, n = 26) in microplots where the M/L layer were present at the time of the fire, and 3900 (SD = 3900, n = 12) in microplots where the M/L layer had been removed.

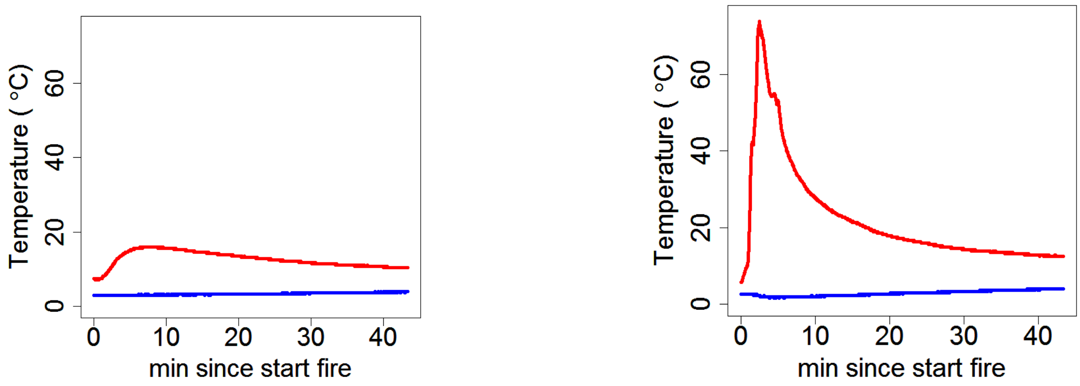

Figure 2. Temperature-time curves during a fire from a microplot with (left) and without (right) the moss and litter layer. Red and blue lines indicate temperatures measured at the top of the peat and 2cm below, respectively.

The peat microclimate data showed that burnt microplots presented higher below-ground daily temperature fluctuations than control microplots. Diurnal fluctuations were further increased in microplots where the M/L layer had been removed (Figure 3). A provisional seasonal linear model was fitted to the data and it was found that mean daily temperature was higher in burnt and burnt and M/L layer removed microplots in spring and summer but the opposite was true in autumn and winter (Figure 4).

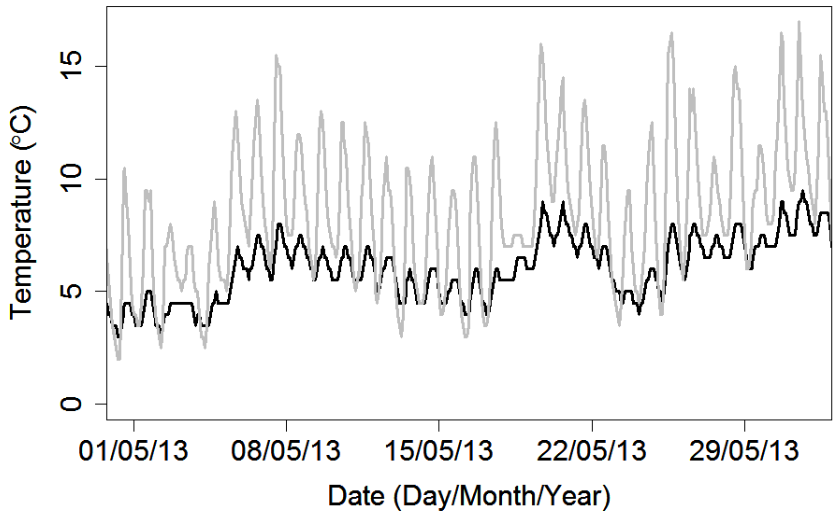

Figure 3. Post-fire peat micro-climate at 2cm depth in a control microplot (black line) and in a burnt microplot where the M/L had been removed (grey line).

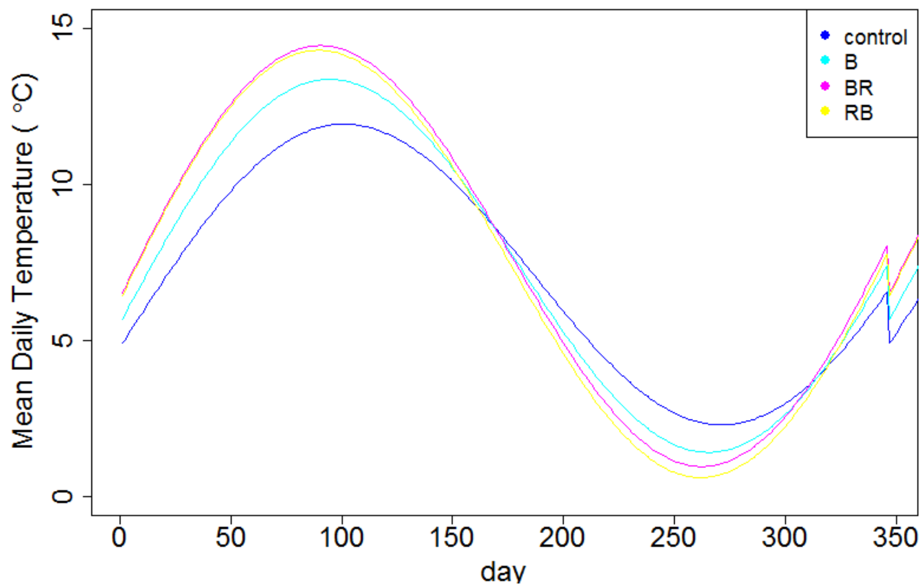

Figure 4. Predicted mean peat temperature values of the seasonal model for the four different treatments. Sampling started in April 2013 and finished in April 2014. "control", unburnt microplots; "B", burnt microplots; "BR", burnt microplots where the M/L layer was removed after the fire; "RB", burnt microplots where the M/L layer was removed before the fire.

3.2. The effect of drought on ground fuel moisture content, flammability and fire severity

Rain-out shelters reduced the FMC of the M/L layer in dry heath from an average of 304% in dry base (SD = 186, n = 16) to 124% (SD = 75%, n = 16). Average M/L layer consumption was 0.7 cm (SD = 1.6, n = 16) in control microplots and 2.4 (SD = 2.4, n = 16) in drought microplots. Microplots burnt under simulated summer drought conditions showed higher temperature residence times than untreated microplots at both the peat surface and at a depth of 2 cm (Figure 5).

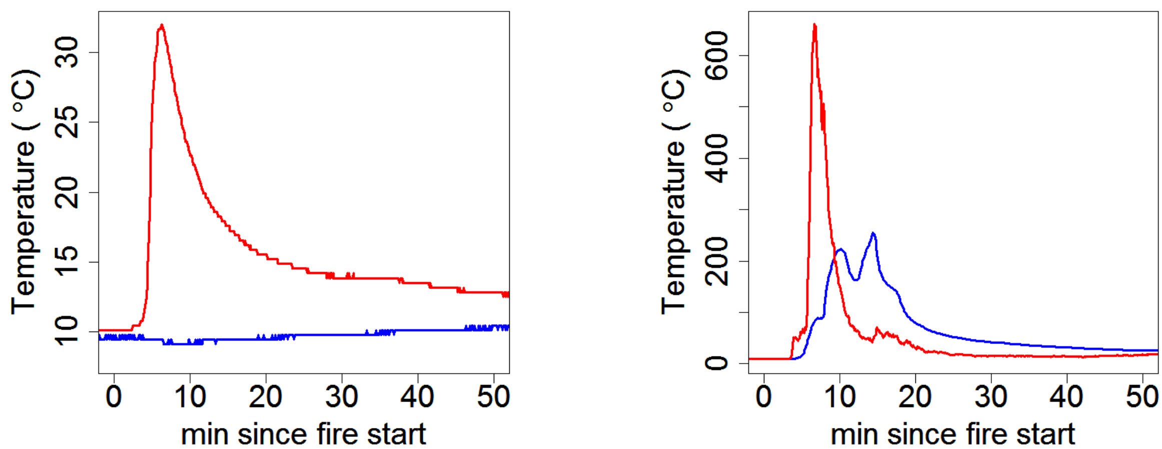

Figure 5. Temperature-time curves during a fire from a control microplot (left) and a drought microplot (right). Red and blue lines indicate temperatures measured at the top of the peat and 2cm below, respectively.

4. Conclusions

Our results show that the M/L layer has a critical ecosystem function by preventing peat from being exposed to significant temperature pulses during burning. The change in fire severity associated with a decrease in the moisture content of the M/L layer under drought conditions could have important implications for peat carbon dynamics and post-fire vegetation regeneration. Variation in fire severity can also drive changes in belowground micro-climate with potentially important implications for soil ecosystem function. On-going work is examining how this variation in fire severity and post-fire microclimate affects carbon fluxes following burning.

5. References

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