Mire microclimate: groundwater buffers temperature in waterlogged versus dry soils

Short title: Testing the thermal buffer of mire groundwater

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12/05/2020

# Graphical abstract



Mires are semi-terrestrial wetlands that remain waterlogged for most of the year. Waterlogged soil experience a thermal buffer effect that isolates them from surrounding temperature variations. This article tests the buffer effect in waterlogged mire soils and adjacent sry soils.

# Abstract

# Keywords

Microniche, fen, bog, dataloggers, azonal habitats, wetlands, Cantabrian Mountains

# Introduction

Climate change (Ipcc [2014](#ref-RN3586)) affects global biodiversity from drylands (Huang et al. [2016](#ref-RN4672)) to forests (Seidl et al. [2017](#ref-RN4673)) and oceans (Hoegh-Guldberg et al. [2017](#ref-RN4674)). Ecosystems can be especially vulnerable when they meet certain criteria (Horsák et al. [2018](#ref-RN4675)): (a) preponderance of species that evolved under a cold climate; (b) low productivity due to nutrient limitation, making them sensitive to increased nutrient cycling caused by warming (Cornelissen et al. [2007](#ref-RN4676)); and (c) scatterred distribution pattern, which limits species dispersal and migration (Pearson and Dawson [2005](#ref-RN4677)). These characteristics are found in temperate peatlands such as mires, i.e. permanent semi-terrestrial wetlands where soils remain waterlogged but not inundated during most of the year (Wheeler and Proctor [2000](#ref-RN3161)). Mires are priority habitats for conservation that harbour high numbers of endangered species (Bergamini et al. [2009](#ref-RN3122)) and support highly-adapted floras in spatially-reduced areas (Grootjans et al. [2006](#ref-RN2960)). Habitat distribution models have predicted a loss of mire surface as a consequence of ongoing climate change (Essl et al. [2012](#ref-RN2937)).

Mires are however azonal habitats whose existence depends on local soil properties (Breckle [2002](#ref-RN3328)): by definition, they are areas with waterlogged soils. Grounwater can produce a buffer effect on soil temperature, keeping soils warmer than the air during cold periods, and vice versa (Ellenberg [1988](#ref-RN3344); Geiger, Aron, and Todhunter [2009](#ref-RN3201)). Root-zone temperature is a major determinant of plant ecophysiology (Körner and Paulsen [2004](#ref-RN3024)), so the groundwater buffer effect is expected to allow mire plants to live along a wider range of air temperatures than they could otherwise. Indeed, mires have a relatively homogeneous flora despite being distributed from Mediterranean to Boreal biomes, and from low valleys to the alpine belt (Peterka et al. [2017](#ref-RN4678)). Recently, soil temperature measurements have become available for mires of North America (Raney, Fridley, and Leopold [2014](#ref-RN3204)), Western Europe (Fernandez-Pascual et al. [2015](#ref-RN2356)) and Central Europe (Horsák et al. [2018](#ref-RN4675)). Their comparison with air temperatures derived from models has shown that mire soils are indeed warmer in winter and cooler in summer, thus giving support to the existence of the groundwater thermal buffer (Fernandez-Pascual et al. [2015](#ref-RN2356); Horsák et al. [2018](#ref-RN4675)). Furthermore, the effect has been linked to the composition of mire flora and fauna (Horsák et al. [2018](#ref-RN4675); Schenková et al., [n.d.](#ref-RN4679)), the growth rings of mire trees (Raney et al. [2016](#ref-RN3060)) and the role of mires as glacial refugia (Jiménez-Alfaro et al. [2016](#ref-RN2513); Dítě et al. [2017](#ref-RN4680)).

It is evident that the groundwater buffer effect will play a determinant role in the response of mire habitats to climate change. As is the case for all azonal habitats, locally measured temperatures are essential to understand this response. Available data recorded temperatures only on the waterlogged soils, using model-derived air temperatures for comparison (Fernandez-Pascual et al. [2015](#ref-RN2356); Horsák et al. [2018](#ref-RN4675); Schenková et al., [n.d.](#ref-RN4679)); or recorded temperatures in both wet and dry spots but for less than a year (Raney, Fridley, and Leopold [2014](#ref-RN3204); Raney et al. [2016](#ref-RN3060)). This article provides the first measurement of the thermal buffer against surrounding non-mire areas, based on soil temperatures recorded during a period of five years. These measures are used to test the hypotheses that, when compared to adjacent dry soils, waterlogged mire soil are (i) warmer in winter and (ii) colder in summer; and have less thermal amplitude in (iii) daily and (iv) annual scales.

# Materials and methods

This study took place in the temperate oceanic region of north-western Spain (43º N, 5º W). Local geography and climate are dominated by the Cantabrian Mountains (> 1500 m above sea level), which run parallel to the coast and trap the prevailing NW Atlantic winds. The resulting humid climate harbours the south-western limit of mire communities in Europe (Jiménez-Alfaro, Díaz González, and Fernández-Pascual [2011](#ref-RN2982); Fernández Prieto, Fernández Ordóñez, and Collado Prieto [1985](#ref-RN3246)). Rain-fed raised bogs and acid valley mires can be found from the coast to just below the treeline, in poorly drained valleys and former glacial lakes. Glacial lakes undergoing silting develop transition mires and quaking bogs communities in the water-to-land transition. Spring fens appear in the mountains above 1000 m; they range from soft-water poor fens on acid bedrocks, to alkaline calcareous fens on limestone.

A selection of 8 mire sites was made, representing the regional elevation gradient of mire vegetation and the different mire types (Table ??)). In each site, two dataloggers (M-Log5W, GeoPrecision, Ettlingen, Germany) were buried at a depth of 5 cm below the upper layer of the soil. They were programmed to record temperature on an hourly basis. One datalogger was placed in a flat waterlogged spot, within the mire. The other dataloggers was placed in the close vicinity, but in a flat and dry area outside the mire. The vegetation was always either mire or pasture, with no shrubs, trees or any other landscape features shading the measuring points. The dataloggers were left on site for approximately five years, after which they were retrieved and their records downloaded. At the moment of retrieval, the internal clock of all the dataloggers had not deviated for more than four hours.

Some steps were taken to clean the logs. First, the records from the first week after installation were removed, to account for the own installation process and the settling of the soils. Second, and because some of the dataloggers had failed at different points in time, a selection was made for each site to keep only time series with records both for the dry and waterlogged points. Afterwards four bioclimatic variables were calculated for each datalogger:

* The mean diurnal range; i.e. the average for the whole period of the daily differences between the maximum and the minimum temperatures recorded in the day.
* The maximum temperature of the warmest month; i.e. the average of the daily maximum records, for the warmst month.
* The minimum temperature of the codlest month; i.e. the average of the daily minimum records, for the coldest month.
* The annual range; i.e. the difference between the maximum temperature of the warmest month and the minimum temperature of the coldest month.

To test if the differences between the dry and the waterlogged points of each site was significant, paired t-tests were used. Tests were one-tailed, according to the following hypotheses: the dry site would have a higher diurnal range, a higher maximum temperature, a lower minimum temperature, and a higher annual range.

# Results

The dataloggers recorded temperatures for five years in five of the sites, four years in two, and two years in one (Fig. 1). A visual inspection of the time series shows more homogeneous temperatures in the waterlogged time series, which are almost always encompassed within the dry time series. The bioclimatic variables (Fig. 2) support this impression. The maximum temperatures of the warmest months are usually higher in the dry measuring points, by more than 6 ºC in some sites, both at low (El Molinucu, La Malva) and high (La Recoleta) elevations. The opposite is true for the minimums of the coldest months, in which case the temperature is generally colder in the dry points, although the difference is less pronounced than for the maximums. The mean diurnal range of temperatures is wider in the dry sites, as is annual temperature range; and again the effect is larger in the low sites and in La Recoleta. The t-tests supported the original hypotheses; namely waterlogged measuring points had (a) smaller diurnal fluctuactions (t = -3.05, p = 0.009, effect size = -2.29 ºC); (b) lower maximums (t = -3.04, p = 0.009, effect size = -4.28 ºC); (c) higher minimums (t = 2.86, p = 0.012, effect size = 0.77 ºC), and (d) smaller annual fluctuations (t = -3.95, p = 0.003, effect size = -5.05 ºC).

# Discussion

The results presented here prove the existence of a thermal buffer effect in waterlogged mire soils, when compared with adjacent dry soils. The mire thermal buffer had been compared previously with air temperatures derived from models, with generally similar results (Fernandez-Pascual et al. [2015](#ref-RN2356); Horsák et al. [2018](#ref-RN4675)). The mire buffer had also been compared to dry soils but only during the growing season (Raney, Fridley, and Leopold [2014](#ref-RN3204); Raney et al. [2016](#ref-RN3060)); our results confirm those findings and extend them to the full year. Therefore, there exists a thermal buffer effect in mire soils that makes their temperatures less extreme than the surrounding landscape. This highlights the importance of using fine-scale microclimatic data to assess vegetation responses to climate change (Storlie et al. [2014](#ref-RN4683)).

One important difference with previous studies is the importance of the buffer during winter. The articles that had used model air temperatures as a control concluded that the buffer effect was stronger at the cold end of the thermal gradient, i.e. in winter and at night (Fernandez-Pascual et al. [2015](#ref-RN2356); Horsák et al. [2018](#ref-RN4675)). In the case of this investigation, the situation was reverse: the effect was weaker when considering the minimum temperatures of the cold period. This indicates the importance of identifying root temperatures when working with plant communities. At high elevations of the study region, the soil can remain covered by snow for periods of winter, and this has its own insulating effect on soil temperatures, an effect which is not captured when using model derived air temperatures (Körner [2003](#ref-RN2392)). Nonetheless, these records were made in South-Western Euope, and they should be repeated at more northern latitudes, where the winter effect may be more relevant (Fernandez-Pascual et al. [2015](#ref-RN2356); Horsák et al. [2018](#ref-RN4675)).

The buffering effect was much stronger during the summer. This was most noticeable in the two lowest elevations. Specially in La Malva, very high temperatures (> 40ºC) were recorded during summer. This site is in a south-facing slope on limestone, a place experiencing sub-Mediterranean conditions at the micro-scale (Sánchez de Dios, Benito-Garzón, and Sainz-Ollero [2009](#ref-RN4681)). This suggests the importance of groundwater in the existence of mire vegetation in Mediterranean areas (Hoyos et al., [n.d.](#ref-RN4682)), not only from the water-availability aspect, but also providing cooling regulation during summer (Ellenberg [1988](#ref-RN3344)).

In summary, this article shows that waterlogged mire soils have a thermal buffer when compared to adjacent soils, contributing to their behaviour as mild island habitats in a landscape that can be more thermally variable (Horsák et al. [2018](#ref-RN4675)). The effect occurs during cold and warm periods, but it is stronger during the summer at least in the study area. Future recording schemes are needed to obtain local soil temperatures from other latitudes, and from more microtopographies within the same mire.

# Data availability

Upon publication, the original temperature records along with R analysis scripts will be uploaded to a public repository in GitHub.

# Acknowledgements

E.F.P. received financial support from the Government of Asturias and the FP7 – Marie Curie - COFUND programme of the European Commission (Grant ‘Clarín’ ACB17-19).

# Tables

Mire sites included in this study, indicating the type of fen, the elevation, coordinates, and length of the temperature recording period.

| Site | Habitat | Elevation (m) | Latitude (ÂºC) | Longitude (ÂºC) | Records (days) |
| --- | --- | --- | --- | --- | --- |
| El Molinucu | Raised bog | 284 | 43.3943 | -5.5376 | 1421 |
| El Riotuertu | Alkaline fen | 1820 | 43.0116 | -5.9465 | 1852 |
| La Bruxa | Alkaline fen | 1528 | 43.0252 | -6.2099 | 1850 |
| La Malva | Alkaline fen | 700 | 43.1196 | -6.2528 | 1347 |
| La Recoleta | Quaking bog | 1768 | 43.0186 | -6.1097 | 1854 |
| La Vega Comeya | Raised bog | 822 | 43.2876 | -4.9874 | 664 |
| La Vega Lliordes | Alkaline fen | 1878 | 43.1523 | -4.8452 | 1809 |
| La Veiga Cimera | Acid fen | 1552 | 43.0272 | -6.2524 | 1850 |

# Figures

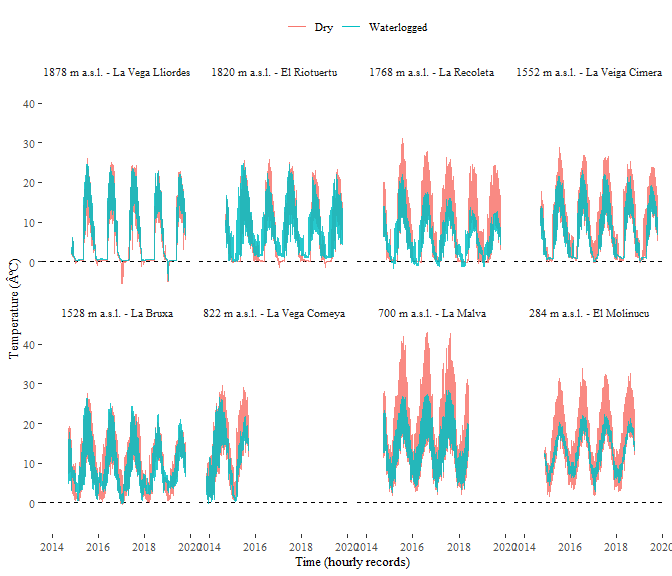


Figure 1: Hourly soil temperature records at the mire sites. The blue series was recorded within the mire, in a waterloged area. The red series was recorded in a neighbouring dry area. Dataloggers were buried at 5 cm depth.

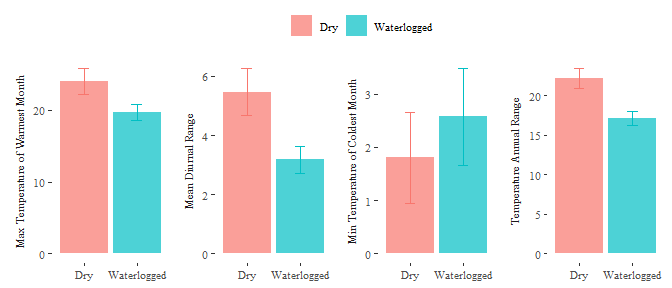


Figure 2: Average bioclimatic variables in the dry and waterlogged sites. The bars represent the mean value, and the bars the standard error of 8 records

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