



1 **Heather management modifies climate sensitivity of surface peat moisture**
2 **in UK upland peatlands**

3 Authors: Bing Liu¹, Andreas Heinemeyer^{1*}, Anthony Lloyd Jones¹; Tom Holmes¹, Milly
4 Outhwaite²

5 *Corresponding author: Andreas Heinemeyer; andreas.heinemeyer@york.ac.uk

6 ¹University of York, Stockholm Environment Institute (York Centre), Wentworth Way,
7 Heslington, York YO10 5NG, UK

8 ²University of York, Department of Environment and Geography, Wentworth Way,
9 Heslington, York YO10 5NG, UK

10

11 **Abstract**

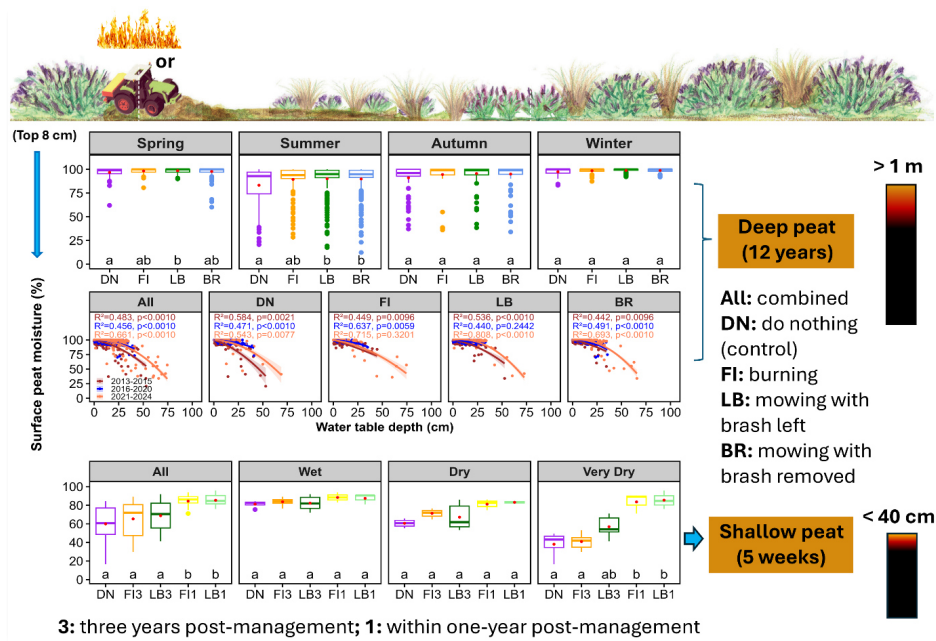
12 UK upland peatlands are important carbon stores, often dominated by heather, and are
13 increasingly threatened by climate change, which promotes peat drying and wildfire risk.
14 While water table depth (WTD) is often monitored to assess peatland hydrology, many key
15 ecohydrological processes depend on surface peat moisture (SPM), which directly regulates
16 surface carbon cycling, vegetation dynamics and peat fire risk, yet SPM remains poorly
17 understood. We analysed seasonal SPM measurements under unmanaged, mown and burnt
18 heather over 12 consecutive years post management from three replicated deep peat sites,
19 together with measurements over five weeks of wet to dry conditions at a shallow peat site
20 spanning three years post management. Across the deep peat sites, climate primarily
21 controlled SPM, while heather management buffered moisture losses, particularly during
22 warm and dry conditions. This buffering effect was strongest soon after management and
23 weakened during vegetation recovery as heather height increased. After excluding low-



24 rainfall events, SPM was strongly related to WTD, and the relationship remained relatively
25 stable when the water table was within ~35 cm of the peat surface. At the shallow peat site,
26 management substantially increased SPM during the first year after treatment relative to old
27 heather, while mowing maintained higher SPM three years post-management, particularly
28 under very dry conditions. Overall, heather management increased SPM across both peatland
29 types, creating wetter near-surface conditions and reducing the sensitivity of surface-moisture
30 to climatic drying. While mowing generally produced more consistent increases in SPM than
31 burning, retained brash may increase wildfire risk under future climate change. The relative
32 benefits of management types are likely to depend on site-specific conditions and time since
33 management.

35 **Key words:** blanket bog, deep peat, shallow peat, peatland restoration, hydrology

Graphical abstract





36 1. Introduction

37 Peatlands cover only around 3% of the global land surface but store approximately 30% of
38 global soil carbon (Yu et al., 2010). These carbon stocks have accumulated over millennia
39 under waterlogged, often cold and acidic conditions that suppress organic matter
40 decomposition (Heinemeyer et al., 2010). However, climate change and human disturbance
41 increasingly threaten peatland hydrological functioning, potentially increasing peat drying,
42 carbon loss and wildfire risk (de Waard et al., 2024; Harenda et al., 2018; Loisel et al., 2021).
43 Protecting and restoring peatlands is therefore of global importance for conserving existing
44 carbon stocks (Andersen et al., 2017; Humpenöder et al., 2020), and supporting climate-
45 change mitigation (Leifeld & Menichetti, 2018).

46 Blanket bogs are the dominant peatland type in the UK, covering more than half of the
47 uplands (IUCN, 2018) and representing around 13% of the global blanket bog resource
48 (IUCN, 2011). Many are dominated by *Calluna vulgaris* (heather) and have historically often
49 been managed by rotational prescribed burning for livestock grazing and grouse moor
50 management (Davies et al., 2016). However, approximately 80% of peatlands are claimed to
51 be degraded (IUCN, 2025), and less than 20% of UK blanket bogs are considered either
52 undamaged (IUCN, 2011) or in “good” condition (IUCN, 2024). While the extent and causes
53 of blanket bog degradation remain contested (Davies et al., 2016; IUCN, 2024, 2025; Tallis,
54 1998), drainage, vegetation change and severe fire can impair peatland long-term functioning
55 (Harper et al., 2018; Heinemeyer et al., 2023a, 2025). Management should therefore be
56 evaluated using direct measurements of ecosystem processes and functions rather than binary
57 pass/fail criteria based on vegetation or management condition alone (Davies et al., 2016;
58 Heinemeyer et al., 2019a, 2025). An important unresolved question is whether heather
59 management alters the capacity of peatlands to retain near-surface water under changing
60 climatic conditions, thereby influencing the resilience of key ecohydrological functions.



61 Hydrological assessments of heather management have primarily focused on water table
62 depth (WTD) (Holden et al., 2015; Worrall et al., 2013), infiltration (Holden, 2009; Jordán et
63 al., 2010; Mallik & Rahman, 1985), hydraulic conductivity (Holden et al., 2014), water
64 storage and flow (Brown et al., 2015; Robinson, 1985), and water quality (Worrall et al.,
65 2007). While WTD is widely used as an indicator of peatland hydrological status, it does not
66 necessarily represent moisture conditions within the biologically active surface peat. Surface
67 peat moisture (SPM) responds directly to rainfall, plant and atmospheric water demand, and
68 regulates vegetation recovery (Mallik et al., 1988), microbial activity (Peltoniemi et al.,
69 2015), carbon cycling (Charman et al., 2013; Räsänen et al., 2021), smouldering fire
70 behaviour (Huang & Rein, 2017) and peatland food webs (Carroll et al., 2015). Satellite-
71 derived SPM has recently been used to assess drought resilience (Lees et al., 2021) and
72 methane emissions (Räsänen et al., 2021), but direct field measurements remain scarce. Only
73 one unpublished UK blanket bog study has directly compared SPM between burnt and
74 unburnt plots over five months following prescribed burning (Meyles, 2002); SPM changed
75 little during burning but was higher in burnt plots under subsequent dry summer conditions,
76 suggesting that management effects may become most apparent during climatic
77 drying. However, that study was short-term, considered only burning and did not assess
78 whether management effects changed as vegetation recovered. Most peatland hydrological
79 studies have also focused on deep peat, leaving responses in shallow peat (i.e., <40 cm)
80 poorly understood.

81 The relationship between WTD and SPM is crucial for predicting carbon emissions (Räsänen
82 et al., 2021), food web interactions (Carroll et al., 2015), and peat-fire risk (Kartiwa et al.,
83 2023). In raised bogs and lowland peatlands, deeper water tables are generally associated
84 with lower SPM (Liu et al., 2019; Price, 1997), although this relationship may weaken when
85 WTD falls ~30-40 cm below the peat surface (Price & Whitehead, 2001; Strack & Price,



2009). Antecedent rainfall may further modify this relationship as small rainfall events can rewet surface peat without producing a response in deeper water table. Such decoupling may be especially important in spatially heterogeneous upland peatlands, which typically include steeper slopes (Bonn et al., 2016) and often contain shallow peat. Determining whether heather management alters the sensitivity of this relationship to contrasting climatic conditions is therefore essential for understanding peatland ecohydrological resilience and wildfire risk under future climate change.

Prescribed burning and mowing may modify the climatic sensitivity of SPM by altering vegetation structure, evapotranspiration and near-surface water retention. Removing mature heather may initially reduce transpiration and root water uptake, thereby limiting moisture loss during warm and dry conditions (Heinemeyer et al., 2023b; Worrall et al., 2013). These effects are likely to weaken as heather regenerates and vegetation-mediated water loss increases. Burning and mowing may also differ in their effects: mowing can leave a brash layer that likely reduces direct evaporation and surface runoff, whereas brash removal exposes the peat surface, and burning may also alter surface properties and infiltration (Heinemeyer et al., 2023b; Holden et al., 2014; Mallik & Rahman, 1985). While mowing has been promoted as an alternative to burning (Heinemeyer et al., 2019a), its ecohydrological effects and long-term trajectories are even less well understood (Harper et al., 2018; Heinemeyer et al., 2019a, 2019b, 2025). Management effects should therefore be examined in relation to peatland type, climatic conditions and time since treatment.

To address these knowledge gaps, we measured SPM (i.e., top 8 cm) under prescribed burning, mowing with brash left or removed, and unmanaged heather. We combined seasonal measurements collected over 12 consecutive years post management at three replicated deep peat blanket bog sites with five-week measurements spanning wet to very dry summer conditions over three years post management at a shallow peat site to answer four questions:



111 (1) How do site characteristics like climate, vegetation, peat depth, and topography influence
112 SPM across deep-peat sites; (2) How do heather management strategies affect SPM and do
113 their effects vary with climatic conditions and time since management; (3) how does WTD
114 relate to SPM under different heather managements in deep peat; (4) how does heather
115 management affect SPM in shallow peat under variable moisture conditions?

116

117 **2. Materials and Methods**

118 **2.1 Study sites**

119 The study was conducted across three deep peat (> 1 m) upland blanket bog sites,
120 Nidderdale (Nidd), Mossdale (Moss) and Whitendale (Whit), and one shallow peat (< 40
121 cm) case-study site, Snilesworth. The deep peat sites are all located in northern England
122 (Heinemeyer et al., 2019a), among which Nidd and Moss are in the Yorkshire Dales and
123 Whit in the Forest of Bowland in Lancashire, with an elevation around 450, 410, 390 m
124 a.s.l and mean peat depths of around 1.6, 1.2, 1.7 m, respectively. The mean annual
125 rainfall during 2012-2024 separates the sites into Nidd being the driest (1434 mm), Moss
126 the wettest (1895 mm), and Whit the intermediate site (1778 mm); mean annual air
127 temperatures were similar among sites, at 7.5 °C, 7.4 °C, and 7.8 °C, respectively
128 (Figures S1-S3). The three sites were previously managed to promote red grouse
129 populations and facilitate sheep-grazing, with an average burn rotation of 22 years
130 (Heinemeyer et al., 2018), two of which (Nidd and Moss) had a long history of rotational
131 vegetation burning (more than 100 years; based on estate information). Moreover, in
132 mature vegetation areas, all sites show more than 50% cover of *Calluna vulgaris*
133 (heather), alongside the presence of characteristic bog vegetation including *Eriophorum*
134 species (cotton-grass, forming some tussocks) and various *Sphagnum* mosses. While



135 Nidd and Moss had some old and mostly infilled drainage grips at low density, Whit
136 without grips included some natural gullies. All sites have low sheep stocking densities
137 of < 0.5 ewes ha^{-1} and each offered two adjacent (Nidd, Moss) or closely located (Whit)
138 sub-catchments of similar size (~ 10 ha). Detailed information about these three sites is
139 described in Heinemeyer et al. (2019a, pp. 23-27). The shallow peat site is in the North
140 York Moors National Park at around 300 m a.s.l. (54.3564 latitude, - 1.22969 longitude;
141 UK Grid Ref SE 501959; Figure S4), with an average peat depth of 18.3 cm at the study
142 locations, ranging from 5 to 29 cm. During the five-week fieldwork period from
143 10/07/2024 to 15/08/2024, the average air temperature and total rainfall was 14.9 °C, and
144 74.7 mm, respectively (Figure S5). This shallow peat site was chosen as a case study to
145 compare how SPM responses to the same management practices differ between shallow
146 and deep peat sites.

147 2.2 Experimental design

148 At the deep peat sites, each sub-catchment was managed in patches across the catchment
149 in 2013 (and other patches in different years since), either by prescribed fire/burning
150 (FI), or mowing with leaving brash (LB) or brash removed (BR) in each site
151 (Heinemeyer et al., 2019a). Within each sub-catchment, four blocks were established,
152 each separated by at least 50 m. In each block, two 5 x 5 m plot-level replicates, spaced 5
153 m apart, were applied to each management, including an additional unmanaged control
154 (DN: do nothing) plot in each block within the mown sub-catchment. In each plot, a
155 water table depth (WTD) meter (WT-HR 1000, TruTrack, New Zealand) was installed in
156 a 1 m deep hole cored into the peat, and a steel peat rod (12 mm diameter) was inserted
157 into the underlying bedrock to monitor peat accumulation and moisture-induced changes
158 in peat depth (i.e., “bog breathing”) (Morton & Heinemeyer, 2019). Moreover, an
159 automated (hourly records) weather station (AWS, MiniMet, Skye Instruments Ltd,



Llandrindod Wells, UK) was located between the two sub-catchments. Overall, the entire manipulative experiment followed a Before-After-Control-Impact (BACI) design (Wauchope et al., 2020), allowing for robust statistical analysis of treatment effects. Almost a full year of pre-management monitoring was conducted; however, SPM was only monitored post-management. Detailed information about the experimental design is described in Heinemeyer et al. (2019a, pp. 27-29). At the shallow peat site, all three management strategies were present, but mowing with brash left was only implemented recently across the estate. The plots were located within an area of ~0.6 km², with a slope of no more than 2°, and all locations shared similar environmental conditions. Six plots were chosen for each of the three management strategies (i.e., DN: ~20-year-old heather, FI3: burnt in 2021, LB3: mown in 2021) to investigate short-term heather management impacts. An additional three plots were chosen from recently managed areas (FI1: burnt in 2024, LB1: mown in 2024) to capture immediate effects. A similar weather station to that used at the deep peat sites was established within the monitoring area.

2.3 Data collection

2.3.1 Weather data

The AWS recorded hourly measurements of photosynthetically active radiation (PAR) at 2 m above ground level; air temperature (T_{air}) and relative humidity (RH) at 1.5 m; precipitation at ground level; and soil temperature (T_{soil}) at 8 cm below ground at the deep peat sites; climate data were available and collected from 2012 to 2024 (Figures S1-S3). At the shallow peat site, measurements were similar to those in the deep peat system, except that soil temperature was recorded at both 5 cm and 10 cm below the surface, and peat moisture was monitored in the top 8 cm; climate data were collected from 19/06/2024 to 15/08/2024 (Figure S5).



184 **2.3.2 Peat moisture**

185 At the deep peat sites, SPM was measured seasonally at fixed carbon-flux monitoring
186 locations within each study plot, following heather management in 2013.
187 Measurements were taken over the top 8 cm of peat using a HH2 SM200 probe (Delta
188 T Devices, Cambridge, England). This depth corresponds approximately to the
189 effective sensing volume of the probe and captures the biologically active near-
190 surface peat layer, which responds rapidly to rainfall, evapotranspiration and
191 vegetation management, and plays a key role in carbon cycling, vegetation recovery
192 and peat fire susceptibility. After clearing any moss or litter from the surface, the
193 probe was inserted into the peat at three locations within each defined microsite, with
194 moisture readings recorded after 5 seconds and averaged to obtain a single value. At
195 the shallow peat site, the same measurement procedures were followed on each
196 measurement day in 2024 (10 July, 25 July, and 15 August; Figure S5).

197 **2.3.3 Water table depth**

198 Peat WTD was monitored only at the deep peat sites. The installed WTD meters
199 recorded measurements every 6 hours. They were checked regularly (seasonally) and
200 corrected based on manual WTD measurements using a custom-made fibre optic rod
201 and air bubble tube (Heinemeyer et al., 2019a, p. 81). The WTD data were collected
202 from 2012 to 2024 (Figures S1-S3).

203 **2.3.4 Vegetation height, litter and peat depth**

204 At the deep peat sites, heather (*Calluna vulgaris*) height was recorded annually in
205 each plot since 2012, typically in September. Five measurements were taken per plot
206 by holding a ruler vertically and measuring from the litter surface to the top of the
207 heather. Peat depth was recorded manually in July/August 2012 at all plot locations



208 adjacent to the WTD meters. Measurements were taken using commercial drainage
209 rods (Clarke CHT640; 1.5 cm diameter PVC, 92 cm extendable sections with screw
210 fittings) and a measuring tape. The rod was pushed vertically into the ground until it
211 reached the bedrock, and peat depth was measured after removal of the rod. At the
212 shallow peat site, the same procedures for measuring heather height and peat depth
213 were carried out. Moss height and litter/brash depth were only measured at the
214 shallow peat site by clearing a small 5 x 5 cm patch and using a ruler placed against
215 the side of the exposed profile to measure the depth of each layer. These
216 measurements were repeated three times during the fieldwork period, once on each
217 visit.

218 2.4 Data analysis

219 To investigate the impacts of site-specific climatic and environmental conditions on
220 SPM, the beta-inflated regression model (BEINF) was fitted using *gamlss()* function
221 from *gamlss* package in R (version 4.5.1). Fixed effects included rainfall, temperature,
222 heather height, peat depth, (with/without management, slope and aspect; Table S1) while
223 random effects accounted for plots nested within blocks, which were nested within sites,
224 as well as year, with *BEINF()* distribution specified as the response family. Moreover,
225 the Akaike Information Criterion (AIC) function was used to determine the optimal
226 model structure, and the *plot()* function was employed for model diagnostics. Prior to
227 model fitting, measurements with extremely high SPM (> 98%) were excluded to
228 minimise the influence of the strong left-skewness in the data representing extreme
229 wetness conditions, thereby improving model fit. This threshold was determined after
230 testing a range of cut-offs (SPM > 90%, 91% to 100%). Climate data were aggregated
231 over timescales of 3 days, 5 days, 1 week, 2 weeks, and 3 weeks preceding SPM
232 measurement. At Whit, SPM on burning plots was consistently lower throughout



233 compared to unmanaged plots (Figure S6), suggesting that these plots were already drier
234 before treatment. This pattern is supported by the pre-management WTD record reported
235 by Heinemeyer et al. (2023b), which also showed consistently and overall deeper water
236 tables in the burnt plots. Because prescribed burning in 2013 was largely constrained by
237 snow cover, resulting in only limited treatment effects, the observed differences are
238 likely to reflect pre-existing hydrological variation rather than management impacts.
239 Consequently, Whit did not satisfy the assumption of comparable baseline conditions
240 among treatments (or fire impacts) and was excluded from the BEINF model
241 development and subsequent analyses of management effects on SPM in the deep peat
242 system. To assess management effects on SPM at the deep peat sites, Kruskal–Wallis
243 tests (due to non-normal data) were conducted using the *kruskal.test ()* function, followed
244 by post hoc pairwise comparisons using *dunn_test ()* function from the rstatix package
245 with fdr adjustment for multiple testing (Figures S7–S10, Tables S2–S5). Analyses were
246 performed for individual years and three periods defined by both vegetation regrowth
247 stages and climatic characteristics: Period 1 (2013–2015: slow heather regrowth under
248 very dry conditions), Period 2 (2016–2020: increased heather cover under wet
249 conditions), and Period 3 (2021–2024: mature heather stands under dry conditions)
250 (Figures S1–S3). Significance letters were extracted and added to the plots using the
251 multcompView package. Moreover, locally estimated scatterplot smoothing (LOESS)
252 was performed using the *loess ()* function from the stats package with a span of 0.6 to
253 generate smooth curves for each treatment to illustrate their general patterns of change
254 over time.

255 To obtain robust relationships between WTD and SPM, we excluded: 1) observations
256 with standing water ($\text{WTD} < 0$); 2) observations with low total rainfall (< 15 mm) during
257 one-week preceding SPM measurement, and 3) those with $\text{SPM} > 90\%$ when WTD



258 exceeded 35 cm depth to minimize the potential influence of short-term precipitation on
259 SPM (Figure S11). The second threshold was identified by sequentially removing total
260 rainfall intervals (0-2.5, 0-5, 0-7.5, 0-10, 0-15, 0-20, 0-50, 2.5-5, 2.5-10, ..., up to 20-50
261 mm) for each aggregated timescale mentioned above, and assessing model fit, while the
262 third was set by evaluating the ecological plausibility of the WTD–SPM relationship,
263 based on scatterplots generated after applying criterion 1 and 2 (Figure S11). Quadratic
264 regression was then implemented using *lm()* function from stats package to explore this
265 relationship, and the removed data were analysed to partially compare management
266 effects on SPM among treatments. To investigate management effects on SPM in the
267 shallow peat system, boxplots and Kruskal–Wallis tests with pairwise comparisons were
268 performed under wet to very dry conditions, with wetness classification determined by
269 climate conditions (Figures S5 and S12). Linear regression was applied to explore
270 relationships between SPM and peat depth, heather height, moss height, and litter depth,
271 respectively. Finally, annual PAR sum, temperature, WTD, RH and total annual rainfall
272 were used to reveal temporal change patterns in the deep peat system (Figures S1-S3),
273 whereas daily values and aggregated periods of 3 days, 5 days, 1 week, 2 weeks, and 3
274 weeks preceding SPM measurement were applied to the shallow peat system (Figures S5
275 and S12). All analyses and plotting were conducted in R with other key packages not
276 mentioned above including tidyverse, ggplot2, ggpubr, patchwork, broom, ggmap (R
277 Core Team, 2025).

278 3. Results

279 3.1 Influence of overall site conditions and management on surface peat moisture in 280 the deep peat system



281 BEINF model output for the two main sites (NM) indicated substantial effects of both
282 climate and heather management on SPM (Table 1a). In the conditional mean (μ)
283 component, rainfall was significantly positively associated with SPM ($\beta = 0.006 \pm$
284 0.003 , $t = 2.32$, $p = 0.021$) when climate data from the three days preceding SPM
285 measurement was used. In contrast, temperature showed a strongly negative
286 association with SPM ($\beta = -0.124 \pm 0.007$, $t = -17.38$, $p < 0.001$). Regarding
287 management effects, both LB ($\beta = 0.310 \pm 0.112$, $t = 2.75$, $p = 0.006$) and BR ($\beta =$
288 0.282 ± 0.115 , $t = 2.44$, $p = 0.015$) significantly increased the SPM, whereas FI also
289 showed a positive but non-significant effect ($p = 0.23$). While PD showed a
290 marginally positive association ($\beta = 0.001 \pm 0.001$, $t = 1.69$, $p = 0.091$), heather
291 height had no detectable negative effect on SPM ($p = 0.41$); however, when excluding
292 management, heather height showed a highly significant negative relationship ($\beta = -$
293 0.008 ± 0.002 , $t = -3.99$, $p < 0.001$); Table 1b). When longer climate data timescales
294 (5 days, 1 week, 2 weeks, 3 weeks) before SPM measurement were applied, most
295 effects remained consistent, with only the rainfall effect becoming much stronger ($p <$
296 0.001) and the management effects weakening slightly as the timescale increased
297 (Table 1a).

Table 1. Results of beta-inflated regression model (BEINF) testing the effects of climatic and environmental factors on the percentage surface peat moisture (SPM^{98%}) across deep peat sites (NM: combination of Nidd and Moss; 2013-2024). Table 1a reports models including management, while Table 1b excludes management. Rainfall and temperature (temp) were evaluated at five temporal scales (3 days, 5 days, 1 week, 2 weeks, 3 weeks) preceding SPM measurement. Management treatments (conducted in 2013) are relative to the baseline DN ('do nothing' as control). FI = prescribed fire; LB = moving with brush left; BR = moving with brush removed; CV:Ht = *Calluna vulgaris* height; PD = peat depth; Coef. = coefficient; Int. = intercept; β = model estimate; SE = standard error. Bold values denote significant effects ($p < 0.05$).

Coef.	3 days			5 days			1 week			2 weeks			3 weeks		
	β (SE)	t	p	β (SE)	t	p	β (SE)	t	p	β (SE)	t	p	β (SE)	t	p
a. BEINF model with management as a fixed effect															
Int.)	3.271 (0.20)	16.59	<0.001	2.989 (0.21)	14.23	<0.001	2.943 (0.22)	13.23	<0.001	2.763 (0.24)	11.61	<0.001	2.655 (0.23)	11.64	<0.001
Rainfall	0.006 (<0.01)	2.32	0.021	0.009 (<0.01)	3.80	<0.001	0.006 (<0.01)	2.94	0.003	0.004 (<0.01)	3.79	<0.001	0.005 (<0.01)	6.60	<0.001
Temp	-0.124 (0.01)	-17.38	<0.001	-0.109 (0.01)	-14.78	<0.001	-0.104 (0.01)	-12.33	<0.001	-0.093 (0.01)	-10.02	<0.001	-0.102 (0.01)	-11.43	<0.001
FI	0.160 (0.13)	1.20	0.232	0.151 (0.14)	1.11	0.268	0.137 (0.14)	0.99	0.320	0.116 (0.14)	0.84	0.402	0.111 (0.14)	0.82	0.415
LB	0.310 (0.11)	2.75	0.006	0.302 (0.11)	2.64	0.009	0.283 (0.12)	2.45	0.015	0.258 (0.12)	2.21	0.027	0.256 (0.12)	2.22	0.027
BR	0.282 (0.12)	2.44	0.015	0.267 (0.12)	2.27	0.023	0.254 (0.12)	2.14	0.033	0.233 (0.12)	1.95	0.052	0.237 (0.12)	2.00	0.046
CV:Ht	-0.003 (<0.01)	-0.82	0.414	-0.003 (<0.01)	-0.74	0.459	-0.003 (<0.01)	-0.81	0.417	-0.004 (<0.01)	-0.98	0.327	-0.004 (<0.01)	-1.10	0.273
PD	0.001 (<0.01)	1.69	0.091	0.001 (<0.01)	1.79	0.074	0.001 (<0.01)	1.56	0.118	0.001 (<0.01)	1.37	0.170	0.001 (<0.01)	1.49	0.136
b. BEINF model without management as a fixed effect															
Int.)	3.590 (0.15)	23.37	<0.001	3.305 (0.16)	20.49	<0.001	3.244 (0.17)	18.68	<0.001	3.036 (0.19)	16.30	<0.001	2.923 (0.18)	16.47	<0.001
Rainfall	0.006 (<0.01)	2.29	0.022	0.009 (<0.01)	3.79	<0.001	0.005 (<0.01)	2.89	0.004	0.004 (<0.01)	3.82	<0.001	0.005 (<0.01)	6.64	<0.001
Temp	-0.124 (<0.01)	-17.51	<0.001	-0.109 (<0.01)	-14.82	<0.001	-0.104 (<0.01)	-12.36	<0.001	-0.094 (<0.01)	-10.07	<0.001	-0.102 (<0.01)	-11.46	<0.001
CV:Ht	-0.008 (<0.01)	-3.99	<0.001	-0.008 (<0.01)	-3.82	<0.001	-0.008 (<0.01)	-3.80	<0.001	-0.008 (<0.01)	-3.86	<0.001	-0.008 (<0.01)	-4.04	<0.001
PD	0.001 (<0.01)	1.73	0.085	0.001 (<0.01)	1.79	0.074	0.001 (<0.01)	1.55	0.121	0.001 (<0.01)	1.36	0.173	0.001 (<0.01)	1.49	0.137



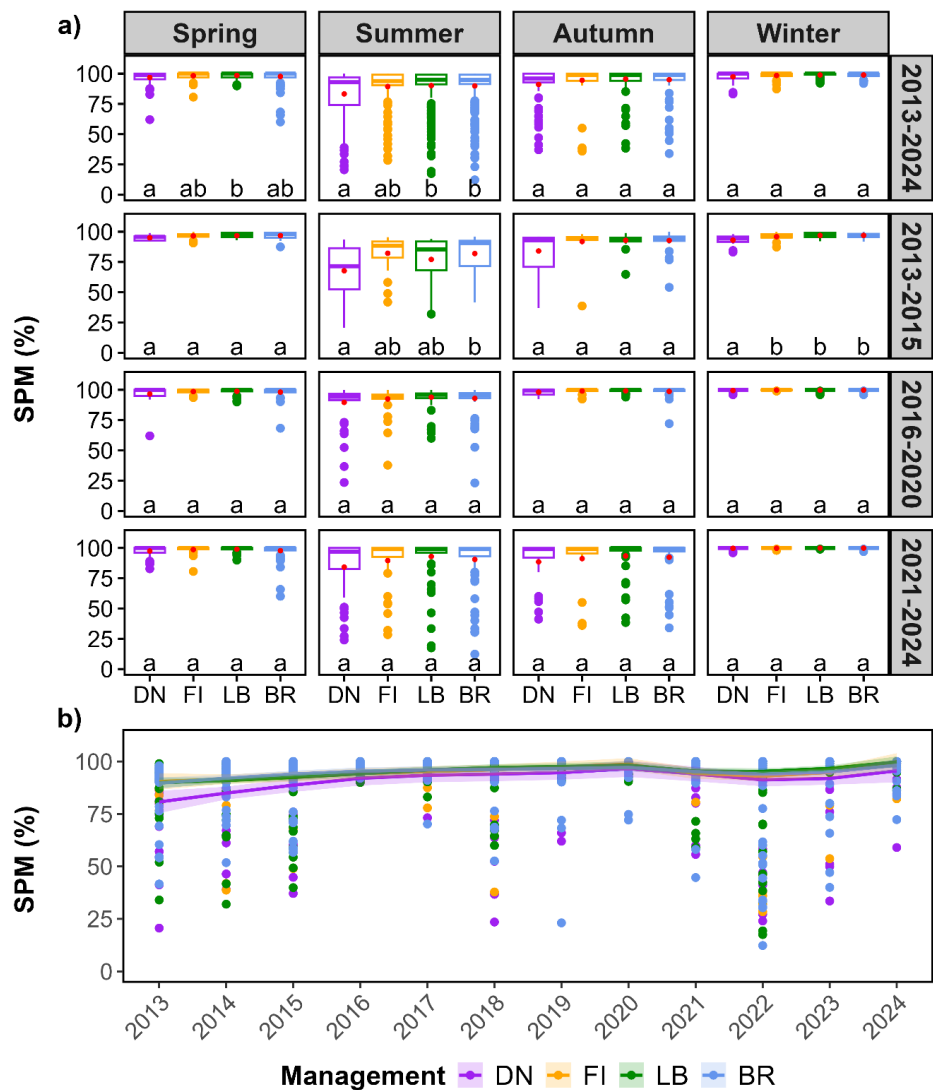


3.2 Effects of heather management on seasonal and period-specific surface peat moisture in the deep peat system

Boxplots of SPM across management types for each year in the two main sites (NM) revealed clear seasonal (Figure 1a) and interannual differences (Figures 1b, S7 and Table S2). In 2013, the Kruskal-Wallis test indicated a marginal overall difference in SPM among management types in summer ($H(3) = 7.53, p = 0.057$) but not in autumn and winter. Post-hoc Dunn's tests with FDR correction showed that SPM was significantly higher in LB ($z = 2.54, p = 0.041$) and BR ($z = 2.46, p = 0.041$) compared to DN. While FI also showed a higher median SPM than DN, this difference was not statistically significant ($p = 0.151$). In 2014 and 2015, a similar pattern was found to that in 2013, with median SPM overall higher (but slightly less pronounced) in the managed plots than in DN during summer. Interestingly, the mean SPM in LB was lower than in both FI and BR, particularly during summer. While SPM in managed plots was significantly higher than in DN in 2015 spring and winter (marginally so for FI), the median difference between them was not as large as that in summer (Figure S7 and Table S2). Noticeably, the large median difference in SPM between managed plots and DN evident in previous summers was not observed in the subsequent study years except in the warmest and dry year 2022 (Figures S1-S3), nor was it apparent in other seasons, although SPM in LB ($z = 2.62, p = 0.041$) and BR ($z = 2.46, p = 0.041$) was marginally significantly higher than in DN in winter 2016. After grouping the years, the stepwise changes in SPM over time following management became clearer (Figure 1). Overall, SPM differed significantly among management types in summer ($H(3) = 9.38, p = 0.025$), with LB ($z = 2.80, p = 0.005$) and BR ($z = 2.72, p = 0.006$) significantly higher than DN (Figure 1a). In spring, SPM also differed significantly among management types ($H(3) = 8.91, p = 0.031$);



329 however, only LB ($z = 2.93$, $p = 0.003$) was higher than DN, and the effect was less
330 pronounced, especially in the mean values (Figure 1a, Table S6). Across time periods,
331 significant differences among management types were detected only in Period 1
332 (2013-2015), in both summer and winter. Notably, both the median and mean SPM in
333 LB were lower than in FI and BR during the summer of Period 1 (Table S6). The
334 differences in SPM between managed plots and DN were greatest in the summer of
335 Period 1 but became less pronounced in Periods 2 (2016-2020) and 3 (2021-2024)
336 (Figure 1a). More clearly, the loess curves (Figure 1b) showed the largest differences
337 in SPM between managed plots and DN in Period 1, the smallest differences in Period
338 2, and intermediate differences in Period 3.



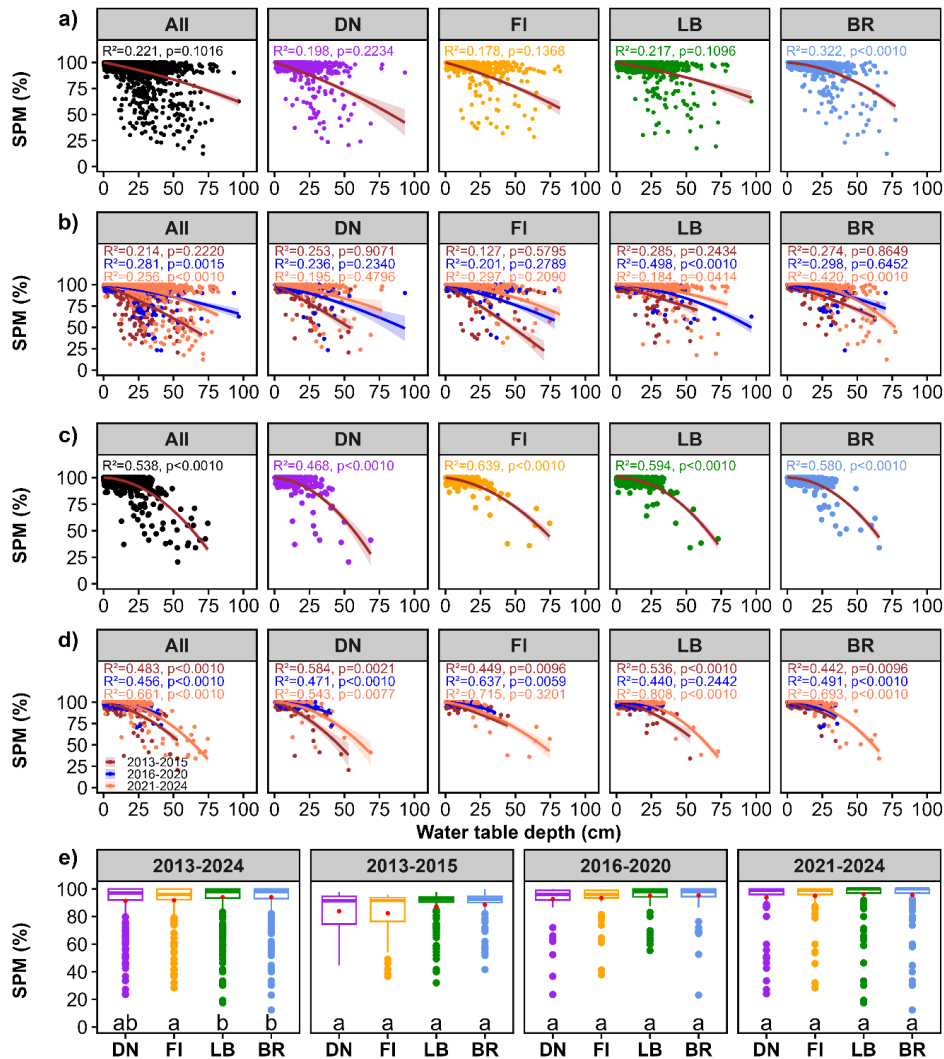
339

340 **Figure 1.** Effects of heather management and climate on percentage surface peat moisture (SPM) across deep peat
341 sites (NM: combination of Nidd and Moss; 2013–2024). (a) Seasonal and periodic (all years vs. three periods)
342 variation in SPM among management types; (b) annual trends with LOESS curve and 95% confidence intervals.
343 Boxplots show the median (50%), interquartile range (25–75%), and variability for each treatment: DN = do
344 nothing (control); FI = prescribed fire; LB = mowing with brash left; BR = mowing with brash removed. Red
345 points represent means; different letters denote significant differences ($p < 0.05$).



3.3 Relationship between surface peat moisture and water table depth in the deep peat system

When data with standing water ($WTD < 0$) were excluded, the combined dataset (All) and most management types (DN, FI, LB) indicated only weak and non-significant relationships between SPM and WTD (Figures 2a and S13a). While a few management-period combinations (i.e., All: 2021-2024, LB: 2016-2020, BR: 2021-2024) showed statistically significant relationships, the remaining combinations displayed weak and non-significant associations (Figure 2b and S13b). After further excluding cases with low amounts of rainfall (< 15 mm) in the week before SPM measurements and those with $SPM > 90\%$ when $WTD > 35$ cm, the relationship became strong and highly significant across all datasets (R^2 : 0.47-0.64, all $p < 0.001$; Figure 2c and S13c). Nearly all management-period combinations also showed strong and highly significant relationships, except for Period 3 in FI ($R^2 = 0.72$, $p = 0.320$) and Period 2 in LB ($R^2 = 0.44$, $p = 0.244$), where the relationships were strong but not statistically significant (Figure 2d and S13d). Moreover, the steepest overall relationship between SPM and WTD was observed in Period 1, with most dry SPM data (Figure 2e) during warm and dry periods in 2013-2014 (Figure S1-S3), followed by Period 3 and then Period 2 (Figure 2d and S13d). For the excluded data, no significant differences among management types were detected in any period (Figure 2e). However, across all periods combined, SPM was significantly higher in LB ($z = 2.86$, $p = 0.025$) and BR ($z = 2.55$, $p = 0.032$) than in FI. Notably, the median SPM in all managed plots was consistently higher than in DN in each period, with LB and BR appearing slightly higher than in FI (Figure 2e and Table S7).



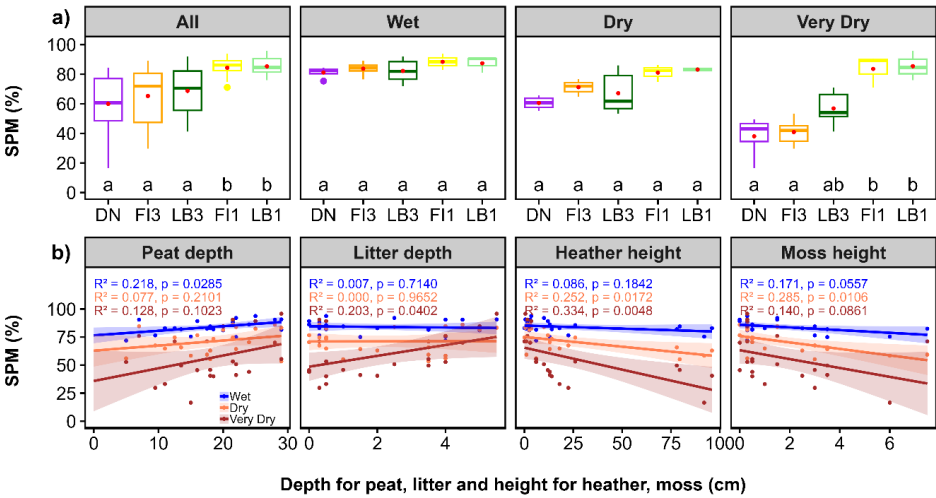
369

370 **Figure 2.** Effects of heather management and climate on the relationship between percentage surface peat
371 moisture (SPM) and water table depth (WTD) across deep peat sites (NMW: combination of Nidd, Moss, and
372 Whit; 2013-2024). (a, b) Relationships excluding observations with standing water, and (c, d) further excluding
373 cases with SPM > 90% when WTD > 35 cm and total rainfall between 0 and 15 mm in the preceding week.
374 Coloured lines show quadratic regression fits with 95% confidence intervals across all years (a, c) or three
375 periods (b, d) for 2013-2015 (brown), 2016-2020 (blue) and 2021-2024 (orange) as shown in (e) periodic
376 differences in SPM among management types for the excluded dataset, with red points representing means. All:
377 all management types combined; DN = do nothing (control); FI = prescribed fire; LB = mowing with brash left;
378 BR = mowing with brash removed. Different letters denote significant differences ($p < 0.05$).



3.4 Effects of heather management on surface peat moisture and its relationship with environmental variables in the shallow peat system

Kruskal-Wallis tests revealed significant differences in SPM among management types shortly after treatment (within one year) under very dry conditions ($H(4) = 15.72, p = 0.003$) and in the combined dataset ($H(4) = 19.49, p < 0.001$), whereas no significant differences were detected under wet and dry conditions (Figure 3a). Specifically, SPM in both FI1 and LB1 was significantly higher than in DN (FI1: $z = 2.61, p = 0.023$; LB1: $z = 2.71, p = 0.023$) and FI3 (FI1: $z = 2.83, p = 0.023$; LB1: $z = 2.94, p = 0.023$) under very dry conditions. A similar pattern was observed in the combined dataset, except for LB3, which was significantly lower than FI1 and LB1. No significant differences were found between managed plots and DN three years post-management. However, noticeably, SPM in LB3 was lower than in FI3 under both wet and dry conditions, but higher under very dry conditions. Additionally, SPM was positively associated with peat ($R^2 = 0.22, p = 0.029$) and litter ($R^2 = 0.20, p = 0.040$) depth, with the effects being significant under wet and very dry conditions, respectively (Figure 3b). In contrast, heather and moss height were negatively correlated with SPM, with significant relationships under either dry or very dry conditions (Figure 3b). Notably, the slope of SPM versus vegetation/litter parameters was greatest under very dry conditions and lowest under wet conditions for all variables, except for litter depth (Figure S14).



399

400 **Figure 3.** Effects of climate, heather management and environmental variables on percentage surface peat
401 moisture (SPM) at the shallow peat site. (a) Differences in SPM among management types under Wet, Dry, Very
402 dry, and (All) combined conditions; (b) linear relationships between SPM and environmental variables with 95%
403 confidence intervals. Boxplots show the median (50%), interquartile range (25–75%), and variability for each
404 treatment: DN = do nothing (control); FI3 = three years after prescribed fire; FI1 = within one year after prescribed
405 fire; LB3 = three years after mowing with brash left. LB1 = within one year after mowing with brash left. In a)
406 red points represent means, and different letters denote significant differences ($p < 0.05$) and b) provides the
407 coefficient of determination (R^2) and p-values for Wet (blue), Dry (orange) and Very dry (brown).

408

409 4. Discussion

410 4.1 Environmental and site-specific controls on surface peat moisture variability

411 The results suggest that climatic factors have the strongest overall effects on SPM
412 across deep peat sites, followed by heather management, with heather height and peat
413 depth having ecologically meaningful but not overall statistically significant
414 influences (Table 1a). However, after excluding management from the BEINF model,
415 heather height effects became highly significant (Table 1b). This could be explained
416 by the higher evaporation rates from unmanaged tall heather biomass (Heinemeyer et
417 al., 2023b; Worrall et al., 2013). Importantly, these findings indicate that climate
418 determines the overall moisture regime, whereas heather management modifies how



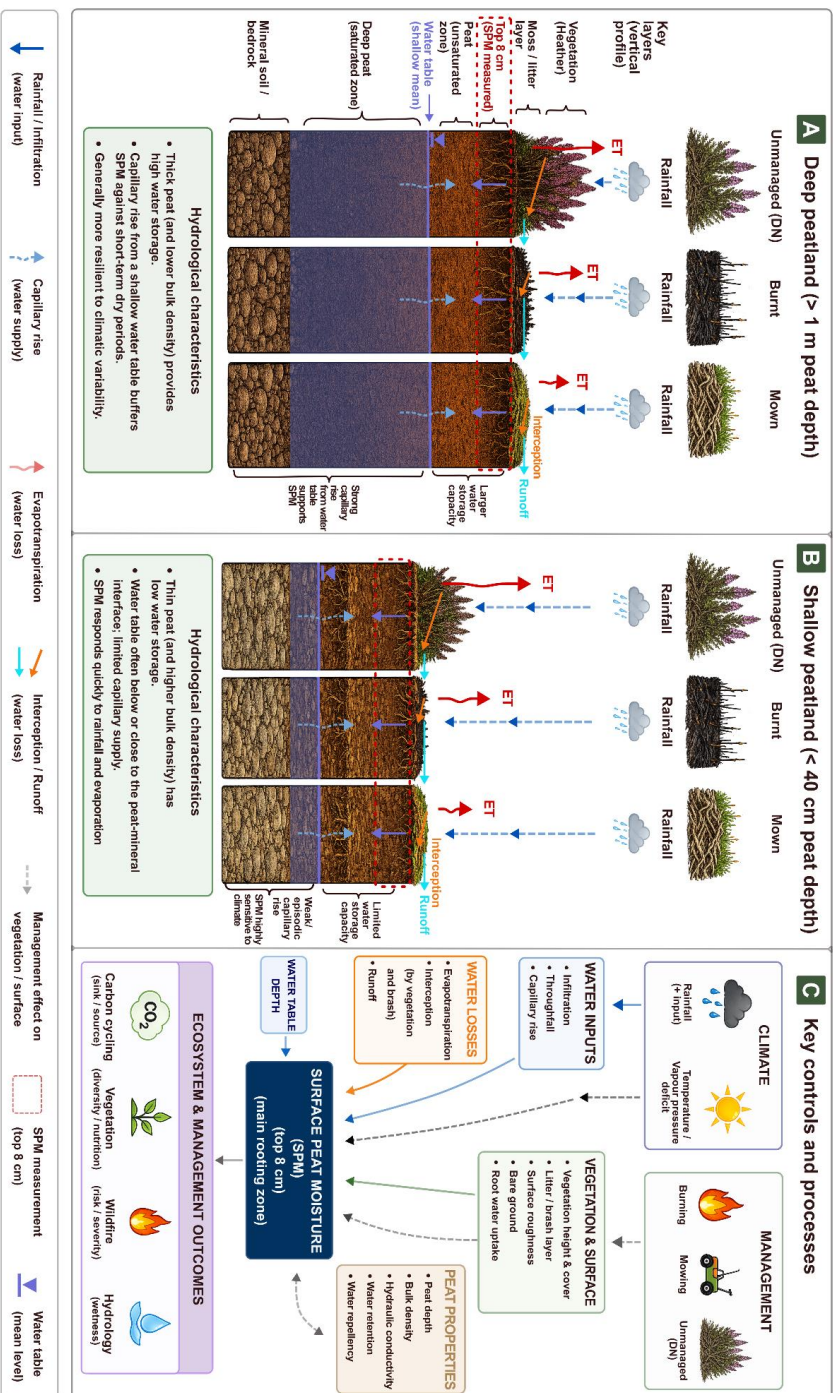
419 surface peat responds to climatic variability. Rather than acting as an independent
420 control of SPM, management alters vegetation structure (Whitehead et al., 2026) and
421 associated evapotranspiration (Worrall et al., 2013), thereby changing the sensitivity
422 of surface peat moisture to rainfall deficits and atmospheric drying (Figure 4).
423 Application of different timescales of climatic factors also had considerable overall
424 impacts (Table 1). This is not surprising as substantial climatic differences, especially
425 in rainfall, existed across the three deep peat sites (Figures S1-S3). The comparatively
426 weaker effects of heather height and peat depth likely reflect their localized and
427 gradual influence on SPM, which is masked by the more pronounced variability
428 associated with climate. As measurements were usually conducted during relatively
429 stable and sunny periods, the preceding three days were also likely to have had dry
430 weather in many cases. However, over longer timescales (e.g., more than five days
431 before measurements), the likelihood of encountering periods with rainfall increased.
432 The likely effects of rainfall, therefore, became stronger with period length, while the
433 contributions of other factors were fairly stable. Nevertheless, vegetation height and
434 peat depth (including litter) showed moderate negative and positive correlations with
435 SPM, respectively, in the shallow peat site, with these relationships generally being
436 more pronounced under very dry than under wet conditions (Figures 3b and S14).
437 These patterns can be attributed primarily to increased evapotranspiration associated
438 with vegetation growth (Helbig et al., 2020) and the enhanced protective effect of
439 thicker litter cover in reducing SPM loss through evaporation (Speranskaya et al.,
440 2024). Moreover, deeper peat generally has greater water storage capacity and can
441 facilitate upward water movement via capillary action (Dixon et al., 2017), helping to
442 retain SPM (Figure 4). Under wetter conditions, the ground is likely too saturated for
443 substantial moisture differences between plots, whereas under drier conditions,



444 vegetation and peat depth exert a stronger influence on surface moisture, amplifying
445 SPM variability across plots. Taken together, these findings highlight the need for
446 caution when using a space-for-time research design to assess heather management
447 impacts (Heinemeyer et al., 2025; Heinemeyer & Ashby, 2023a; Whitehead et al.,
448 2026). Baseline differences between control and treatment plots, driven by climate,
449 topography, vegetation, hydrology and other environmental factors should be
450 considered and ideally accounted for; otherwise, it may be difficult to distinguish
451 management effects from confounding factors (Ashby & Heinemeyer, 2020), as
452 exemplified by the lower pre-management WTD on burnt plots at Whitendale, where
453 the BACI framework helped identify pre-existing hydrological differences
454 (Heinemeyer et al., 2019a)



Conceptual model of surface peat poisture (SPM) controls in deep vs. shallow peatlands under heather management



SPM in the upper 8 cm integrates the effects of climate, vegetation management, water table dynamics and peat properties. These controls differ between deep and shallow peatlands, leading to contrasting moisture regimes and ecosystem responses.

456 **Figure 4.** Conceptual model illustrating the controls on surface peat moisture (SPM) in deep and shallow peatlands under contrasting heather management. Climate regulates
457 SPM through rainfall inputs and evaporative demand, while heather management primarily modifies evapotranspiration, litter cover and surface conditions. Water table depth
458 provides subsurface water supply through capillary rise, particularly in deep peat, whereas shallow peat exhibits lower water storage capacity and greater sensitivity to
459 climatic variability. SPM was measured within the upper 8 cm of peat, representing the biologically active surface layer where hydrological, ecological and fire-related
460 processes are concentrated.

461

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464





4.2 Climatic and management controls on the coupling between surface peat moisture and water table depth

Correlation analysis revealed a weak to moderate but non-significant inverse correlation between SPM and WTD for most management types and the combined deep peat dataset when excluding only cases with standing water (Figure 2a). This may indicate strong climatic impacts, particularly of rainfall, as many samples with high SPM (> 90%) occurred when the WTD was deeper than 50 cm (Figure 2a). It is likely that low amounts of rainfall affect only SPM without influencing WTD, thereby weakening the explanatory power of WTD on SPM variability. After removing such cases of low rainfall (Figure S11), the relationship became strong and significant across all situations, supporting the earlier assumption of pronounced climatic effects. It further suggests that the relationship is stronger and more predictable when WTD is shallower than around 35 cm (Figures 2c and S11).

Periods of wet, dry and very dry conditions clearly influenced the relationship trend, with drier conditions associated with a steeper declining curve, which was particularly evident in DN (Figure 2d). These contrasting climatic periods demonstrated that heather management modified the sensitivity of SPM to climatic drying. Under unmanaged vegetation, SPM declined much more rapidly as WTD deepened during dry periods, whereas managed plots showed considerably smaller differences among climatic periods, indicating that vegetation removal buffered the response of SPM to drought. This pattern is likely attributable to the broader range of rainfall and temperature under drier periods, which, together with evapotranspiration losses, in turn leads to greater variability in both SPM and WTD (Heinemeyer et al., 2019a). While heather management did not alter the overall relationship pattern, it considerably reduced the differences in steepness across climate periods by raising



490 WTD closer to the surface through lowered evapotranspiration (Worrall et al., 2013)
491 and root water uptake (Heinemeyer et al., 2023b), especially pronounced during drier
492 periods (Figures 2d and S13d).

493 The relationship between SPM and WTD is complex, as it is strongly influenced by
494 climatic conditions and vegetation/ground-surface characteristics (Figure 4). While
495 WTD can remain relatively stable, SPM often exhibits high variability, especially
496 under low rainfall conditions. Additionally, this complexity is also affected by “bog
497 breathing” as shown in site- and vegetation-specific changes in peat bulk density, and
498 thus volumetric moisture content, in response to WTD changes (Morton &
499 Heinemeyer, 2019). Therefore, caution is required when using WTD to infer SPM or
500 vice versa. However, our findings support a previously documented WTD threshold
501 of ~35 cm (Price & Whitehead, 2001; Strack & Price, 2009) (here with > 90% SPM)
502 that may serve as a reliable reference for stable WTD-based predictions of SPM, as
503 beyond this point the tight relationship between the two variables diminishes and
504 eventually disconnects. Consequently, WTD alone may not adequately represent
505 overall climate-induced changes within the biologically active surface peat,
506 particularly where vegetation management alters evapotranspiration and rainfall
507 partitioning (interception, infiltration, runoff; Figure 4).

508 **4.3 Contrasting responses in deep and shallow peat settings**

509 Our findings revealed clear seasonal and interannual variations in SPM across deep
510 peat sites, with substantially higher moisture in managed plots than in DN; these
511 differences were most pronounced in summer, particularly during period 1, and
512 diminished over time under similar climatic conditions (Figures 1 and S6-S9). The
513 enhanced management effects during warm and dry summers indicates that heather
514 management primarily reduces the sensitivity of SPM to climatic drying rather than



515 maintaining uniformly wetter conditions throughout the year. Part of these findings
516 align with those of Mallik et al. (1984) and Meyles (2002), who reported higher SPM
517 under burnt than unburnt plots following short-term heather burning experiments.
518 These patterns can largely be explained again by reduced evapotranspiration and root
519 water uptake after the removal of aboveground vegetation (Heinemeyer et al., 2023b;
520 Liu, 2023; Worrall et al., 2013). This mechanism likely also underlies the highly
521 significant negative relationship between heather height and SPM when management
522 was excluded (Table 1b). In summer, these effects peak due to limited rainfall and
523 high temperatures, thereby maximizing SPM differences between managed and DN
524 plots. In winter, however, abundant rainfall and lower evapotranspiration rates
525 saturate the peat and mask the effects of vegetation, resulting in minimal SPM
526 differences. As vegetation regrows, these effects gradually diminish, reducing the
527 SPM differences between managed and DN plots as seen in period 3 compared to
528 period 1 under similar climatic conditions (Figure 1b). By contrast, period 2 was
529 relatively wetter, and SPM was likely affected more by rainfall than by vegetation
530 regeneration, which thereby reduced the differences.

531 Notably, SPM in LB was higher than in both BR and FI over the study period but was
532 overall lower during period 1 (Figure 1a). This may reflect period-specific brash
533 effects. In period 1, brash likely intercepted substantial rainfall, reducing water
534 reaching the ground (Figure 4). While brash can also reduce evaporation by
535 protecting the peat surface, the reduced water recharge seems to have dominated,
536 resulting in drier SPM in LB. As compaction and decomposition progressed, the
537 balance shifted, and after approximately three years post-burn, recharge and
538 protective effects likely began to outweigh interception losses. Consequently, SPM in
539 LB exceeded that in BR and FI during periods 2 and 3. Additionally, the slightly



540 overall lower SPM in FI than in both LB and BR (but still not lower than DN; Table
541 S6) may suggest that prescribed burning has only subtle and limited impacts on peat
542 properties, such as water repellency, infiltration rate, and bulk density (Cawson et al.,
543 2016; DeBano, 2000). However, considering climate change and more frequent
544 extreme drought events in spring and summer, brash layers resulting from mowing
545 may pose an additional wildfire risk from fuel loads (Heinemeyer & Ashby, 2023a).

546 At the shallow peat site, significantly higher SPM in managed than in DN plots was
547 found only within one year following treatment under very dry conditions (Figure 3a).
548 It is unsurprising as shallow peat generally has deeper WTD (in our site mostly within
549 the bedrock) and drier SPM than deep peat (Wilkinson et al., 2020). Under very dry
550 conditions, vegetation in DN plots cannot access sufficient water from underground,
551 leading to a rapid decrease in SPM due to evapotranspiration. However, under wetter
552 conditions, SPM differences between managed and DN plots can be reduced by
553 increased recharge and lower evapotranspiration. In any case, these differences from
554 unmanaged areas are expected to diminish with vegetation regrowth for the reasons
555 outlined above, though the process tends to be faster and more pronounced in the
556 comparatively drier shallow peat system, where conditions favour the rapid regrowth
557 of drought-adapted plants such as heather. Notably, SPM in LB was higher than in
558 both FI and DN three years after management under very dry conditions but lower
559 under wetter conditions; however, within one-year, median SPM in FI was higher
560 than in LB (Figure 3a). This may indicate that mowing with brash left can maintain
561 more water than burning or mowing with brash removed in particularly dry conditions
562 over the longer term (e.g., more than three years) post-management, as observed in
563 deep peat sites (Figure 1a), further highlighting the period-specific brash effects.

564 **4.4 Management implications, limitations and future research**



565 This study shows that heather management reduced the susceptibility of surface peat
566 to climatic drying by maintaining wetter near-surface conditions, particularly during
567 warm and dry periods when ecohydrological functioning is most vulnerable. Such
568 changes are therefore likely to create favourable conditions for the regeneration of
569 hydrophilic vegetation, such as *Sphagnum* mosses, grasses and shrubs, especially in
570 the early stages of recovery as around 50% of fine roots in similar blanket bog were
571 found in the top 5 cm of the measured 20 cm peat profile, and more than 95% of soil
572 respiration took place in the upper 10 cm of peat (Heinemeyer et al., 2011). The driest
573 unmanaged plots in turn highlight the benefits of removing old, dense and tall heather
574 toward supporting rewetting and reducing carbon loss from increased decomposition
575 in drier peat and mitigating the potential rising wildfire risks associated with climate
576 change (Heinemeyer et al., 2025; Liu, 2023), especially considering dead standing
577 heather biomass (Lewis et al., 2024). Additionally, the lower vegetation height and
578 increased SPM likely benefits many moorland birds (e.g., golden plover) by
579 supporting breeding grounds and higher crane fly populations, a key food source,
580 which were observed to prefer a moisture range of 85% to 95% (Carroll et al., 2011;
581 Heinemeyer et al., 2019a). Regarding the optimal management strategy, current
582 evidence remains insufficient to draw firm conclusions, but potential options are
583 likely site-dependent: prescribed burning may be preferred in wetter sites and where
584 mowing is not accessible, whereas mowing with brash left is likely better in drier
585 sites.

586 Overall, our findings indicate that heather management modifies the climate
587 sensitivity of SPM by buffering moisture losses during dry conditions rather than
588 uniformly increasing peat wetness throughout the year. This buffering effect was
589 strongest shortly after management and gradually weakened as vegetation regrew,



590 demonstrating that climate sensitivity of SPM changes dynamically during ecosystem
591 recovery. While these findings were revealed by the long-term experimental design,
592 several limitations should be considered when interpreting the magnitude of
593 management effects. The wider experimental design and pre-management WTD
594 records helped identify baseline hydrological differences, but the absence of pre-
595 management SPM measurements limits attribution of all post-treatment SPM
596 differences exclusively to management. These limitations are also important when
597 comparing our findings with previous studies. For example, Holden et al. (2015)
598 reported the lowest WTD following prescribed burning, but also a gradual increase in
599 WTD (and thus wetness), with the highest WTD occurring in plots more than 10
600 years post burning. However, these results were derived from a space-for-time
601 approach, which is inherently subject to uncertainty arising from pre-existing
602 environmental differences among sites (Ashby & Heinemeyer, 2020). The contrasting
603 conclusions between studies therefore likely reflect methodological differences, pre-
604 existing environmental variation among sites, differing climatic and ecohydrological
605 conditions, the use of environmentally contrasting control sites, and genuine
606 differences between short- and long-term responses to heather management (Ashby &
607 Heinemeyer, 2020; Heinemeyer et al., 2025). These findings also raise several
608 important questions. What constitutes an appropriate reference condition for
609 unmanaged peatlands? Is the recovery trajectory site-dependent? Do both
610 managements support sustainable practice and recovery of ecohydrological functions?
611 Collectively, these findings suggest that vegetation management should be viewed not
612 simply as a means of altering average peat wetness but as a mechanism for enhancing
613 the resilience of near-surface peat moisture to climatic drying under future climate
614 change. Further research is needed to address these questions and improve the



615 mechanistic understanding of SPM dynamics across peatland types and management
616 strategies. In particular, measurements of peat hydraulic properties, including
617 saturated and unsaturated hydraulic conductivity, infiltration capacity, soil water
618 retention characteristics and near-surface runoff (Holden et al., 2014, 2015), would
619 help disentangle the relative contributions of evapotranspiration and water transport
620 processes to the observed management effects on SPM. These measurements would
621 improve understanding of how prescribed burning and mowing influence peat
622 hydrology and provide better parameterisation of ecohydrological models. Future
623 studies should also quantify the rewetting potential and topographic constraints (e.g.,
624 slope and aspect) governing SPM across contrasting peatland types, including "leaky
625 slope" and "soup bowl" systems (Glatzel et al., 2024). In addition, measurements of
626 peat moisture throughout the peat profile, together with long-term monitoring ideally
627 spanning at least one complete management rotation (approximately 5–25 years
628 depending on peatland type), and adequate replication at both plot and site levels, are
629 required to improve model predictions and support evidence-based, sustainable
630 heather management under future climate change.

631

632 **Code and data availability**

633 All code and data can be made available from the corresponding author upon request

634

635 **Author contribution**

636 **Bing Liu:** Data curation, Formal analysis, Investigation, Validation, Visualization, Writing

637 (original draft preparation), Writing (review and editing); **Andreas Heinemeyer:**



638 Conceptualization, Data curation, Funding acquisition, Investigation, Methodology, Project
639 administration, Resources, Supervision, Validation, Writing (review and editing); **Anthony**
640 **Lloyd Jones:** Investigation, Methodology, Writing (review and editing); **Tom Holmes:**
641 Investigation, Methodology, Writing (review and editing); **Milly Outhwaite:** Investigation.

642

643 **Competing interest**

644 The authors received funding from a variety of sources reflecting the wide range of interest in
645 peatland management. The research builds on the Peatland-ES-UK project which is not about
646 grouse moor but heather management for ecosystem services. Importantly, the funders of the
647 Peatland-ES-UK project had no influence on this paper and on balance are likely indifferent
648 or against heather burning, and were from multiple sources, in order of highest amount of
649 funding to lowest these are: Defra, NERC, two water companies, the Law Family Charitable
650 Foundation, the Moorland Association, the British Association of Shooting and Conservation
651 and further smaller funding from the Heather Trust, Yorkshire Peat Partnership, Natural
652 England and the Ecological Continuity Trust.

653

654 **Acknowledgements**

655 We would like to thank all sites for access and various gamekeepers for their support.
656 Funding was provided by the Natural Environment Research Council (NERC) via the IDEAL
657 UK Fire project (NERC NE/X005143/1) and the wider Peatland-ES-UK project funding from
658 various funders including (from highest to lowest support) Defra, NERC, United Utilities,
659 Yorkshire Water Services, the Law Family Charitable Foundation, the Moorland Association,
660 the British Association of Shooting and Conservation and further smaller funding from the



661 Heather Trust, Yorkshire Peat Partnership, Natural England and the Ecological Continuity
662 Trust including funding from the Ramble Worldwide Outdoor Trust .

663

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