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Contextualizing UK moorland burning studies with geographical variables and sponsor identity

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Abstract

1. It has been claimed that geographical variability could alter conclusions from some studies examining the impacts of prescribed moorland burning, including the Effects of Moorland Burning on the Ecohydrology of River basins (EMBER) project. We provide multiple lines of evidence, including additional analyses, to refute these claims. In addition, new findings from EMBER study catchments highlight previously unconsidered issues of burning adjacent to and over watercourses, contrary to guidelines.
2. A systematic review confirms the EMBER conclusions are in line with the majority of published UK studies on responses to prescribed burning of *Sphagnum* growth/abundance, soil properties, hydrological change and both peat exposure and erosion.
3. From this review, we identify an association between sponsor identity and some recent research conclusions related to moorland burning. This additional variable, which has not previously been incorporated into moorland burning policy debates, should be given greater consideration when evidence is being evaluated. We also show that sponsorship and other perceived conflicts of interest were not declared on a recent publication that criticized the EMBER project.
4. *Policy implications*. Effects of Moorland Burning on the Ecohydrology of River basins (EMBER) findings still suggest multiple environmental impacts associated with prescribed vegetation burning on peatland. Non-compliance with guidelines for heather burning alongside/over watercourses merits closer attention. Policy communities might need to consider potential influences associated with funder identity when evaluating studies.

KEYWORDS

aquatic macroinvertebrates, fire, hydrology, peat, prescribed burning, sediment, vegetation

1 | INTRODUCTION

Recent widespread intensification of land management in the UK uplands to support the driven grouse shooting industry (Douglas et al., 2015; Yallop et al., 2006) has led to a situation in which claims and counterclaims about the effects of this practice are now commonplace. These claims often stem from increasingly high-profile unexplained deaths or disappearances of protected birds such as hen harrier *Circus cyaneus* (Murgatroyd et al., 2019) as well as changes in mountain hare *Lepus timidus* populations (Hesford et al., 2019;

Watson & Wilson, 2019). There have also been debates about the effects of changes in vegetation and catchment processes due to vegetation burning (e.g. McCarroll, Chambers, Webb, & Thom, 2016; Yallop, Clutterbuck, & Thacker, 2010).

Ashby and Heinemeyer (2019; 'A&H') added to the debate with their critique of four of the 'Effects of Moorland Burning on the Ecohydrology of River basins' (EMBER) papers published to date. In our view, the A&H paper in several places made unfounded statements apparently intended to undermine all EMBER outputs. A&H suggested that the EMBER work was problematic, proposing that geographical variation had not been considered. The critique represents part of an intense debate about UK moorland burning (Baird et al., 2019; Brown, Holden, & Palmer, 2016; Davies et al., 2016; Douglas, Buchanan, Thompson, & Wilson, 2016; Evans et al., 2019). Most recently, some studies on peat and carbon accumulation (Heinemeyer, Asena, Burn, & Jones, 2018; Marrs et al., 2019b) were suggested to have overstated conclusions due to use of incorrect methods (Young et al., 2019), and these papers have required corrections to clarify perceived competing interests (Heinemeyer et al., 2018; Marrs et al., 2019a). At the same time, as researchers are increasingly required to evidence societal impact of their work, perceived decreases in public funding mean that researchers are seeking to diversify research funding, which may include sponsors with some form of agenda. There has been no detailed analysis of the funding source or competing interests amongst contributors to these debates and, therefore, the extent to which such factors may or may not be influencing the discussion remains unclear.

Here, we address three issues. First, we examine the A&H assertion that geographical variability contributes to false conclusions drawn from EMBER studies. Second, from a review of the current literature, we seek to establish whether EMBER conclusions are in line with published studies on responses to burning of *Sphagnum* growth/abundance, soil properties, hydrological change or peat exposure and erosion. Third, we examine whether sponsor identity might be associated with published research outcomes. We show that: A&H's critique contains multiple incorrect portrayals of where geography (linked to site- and plot-specific analyses) was incorporated in EMBER analyses, and new analyses illustrate this further; we highlight a selective focus of the A&H critique, which ignored papers published since 2017 using EMBER data; we show their concerns about soil temperature responses are unfounded; we demonstrate that EMBER results are in line with the majority of other published studies; we provide new evidence that guidelines on burning near watercourses appear not to have been followed in EMBER study catchments, and we identify the possibility that, in some cases, published evidence could be associated with the particular agenda of sponsors—a concept known as sponsorship bias. We therefore contend that sponsor and other perceived conflicts of interest, in relation to authors of research outputs plus those conducting peer reviews, may need to be considered by journals and policymakers when interpreting research conclusions.

2 | MATERIALS AND METHODS

2.1 | Examination of A&H claims

A&H selectively focused on four publications (Brown, Johnston, Palmer, Aspray, & Holden, 2013; Brown, Palmer, Wearing, Johnston, & Holden, 2015; Holden et al., 2014, 2015), even though EMBER supported three more primary research papers to date (Aspray, Holden, Ledger, Mainstone, & Brown, 2017; Brown et al., 2019; Noble et al., 2018). We perceive the selective focus as an attempt to undermine the entire project. A&H claimed that altitude was unaccounted for in EMBER publications, and that because it would be linked with precipitation and temperature across the study sites, it should have been considered further. Altitude and precipitation data from Table 2 in A&H were assessed using linear regression, and the assessment was repeated with catchment outlet altitude (e.g. Brown et al., 2013). We tested for association between water temperature and catchment outlet altitude (Brown & Holden, 2020; Brown et al., 2013). A&H claimed altitude, catchment size and precipitation effects would likely affect river invertebrates but that this had not been considered even though the original analysis incorporated water temperature (associated with altitude). We fitted catchment size and run-off parameters (associated with precipitation) from Holden et al. (2015) to the non-metric multidimensional scaling (NMDS) solution using the envfit procedure, and assessed community composition data collected in five sampling periods using ANOSIM, as described in Brown et al. (2013). Papers ignored by A&H (Aspray et al., 2017; Brown et al., 2019) suggested that fine particulate organic matter (FPOM) from peat erosion (as expected following vegetation removal with fire) can have significant effects on ecosystem structure and functioning when deposited in rivers. FPOM densities reported by Brown et al. (2013) were tested for association with catchment size and altitude, and with rainfall totals for the month of sampling from the modelled gridded precipitation records used by A&H. FPOM densities and macroinvertebrate community metrics discussed by Brown et al. (2013) were analysed further using mixed-effects models, to assess whether site-specific variables (water temperature, catchment size, geology, flow variables) were associated with responses alongside burn effects (see Supporting Information).

While there are no recorded cases of EMBER 'surface' thermistors being exposed periodically to sunlight and being warmed artificially as claimed by A&H, we tested the effect of this possibility to determine whether it alters conclusions. Statistical models were developed by Brown et al. (2015) to predict daily maximum soil temperature in plots burned 15+ years prior to the study. These models were applied to predict temperatures of plots burned 2, 4 and 7 years previously, with outliers from predicted temperatures (hereafter 'disturbances') enabling estimation of burning effect magnitude. Using the maximum temperature datasets, the top 10% of disturbances, encompassing the peak temperatures commented on by A&H, were discarded, and the analysis re-run following Brown et al. (2015).

2.2 | Review to contextualize EMBER findings

A systematic review of published literature, relevant to burning effects on UK peatland, was undertaken to determine whether EMBER results were out of line with studies undertaken before the project started or in recent years. Web of Knowledge and Google Scholar searches were conducted between 28 June 2019 and 2 July 2019, supplemented with literature provided kindly by A&H from their own search on 27 September 2019 (Supporting Information). We also examined reference lists from recent publications, including other systematic reviews (e.g. Glaves et al., 2013), and from our own knowledge of relevant research outputs. We initially rejected studies not based in the UK uplands, those focusing solely on wildfire effects, review/opinion/comment papers or literature not available publicly for peer review (e.g. reports to water companies, summaries of unpublished data), and those with no obvious relevance to EMBER studies. The initial searches and shortlisting produced 135 potentially relevant peer-reviewed publications.

We reviewed each shortlisted paper focusing particularly on abstract, results, discussion and conclusions to categorize papers according to seven ecosystem properties studied in EMBER (Table 1). Finer scale properties for specific variables (e.g. pH, DOC, EC as part of stream water chemistry) were explored initially but returned low numbers of studies, hence our use of broader groupings. Overall, 68 papers were considered to be directly relevant. Our approach was to categorize papers based on statements and suggestions within each paper, accepting the expert judgement of the scientists involved based on their detailed evaluations of the datasets available to them (see Supporting Information). For four of the properties, we considered it possible to classify suggested responses to vegetation burning as positive, negative or having no/mixed effects (Table 1). We classified such responses when authors of those papers made clear suggestions that there was a burning effect, no burning effect or results were varied/inconclusive respectively. All papers that were found to be relevant to the first four ecosystem properties were classified in terms of a combined effect: + (only positive outcomes suggested across the four properties), − (only negative outcomes suggested) or 0 (no clear outcomes, or a mixture suggested). For the other three ecosystem properties (soil physical/chemical properties, stream water chemistry, hydrology), we classified responses in terms of whether there was a change/difference (yes) or no change/difference (no) suggested. The approach for these three properties was necessary because most of the studies lacked clear statements as to whether effects could be deemed positive or negative for peatland function.

2.3 | Sponsor identity

For each paper, acknowledgements, funding declarations (where present) and/or affiliations were used to determine sponsors and relevant competing interests, then combined into groups for analysis: (a) *Grouse shooting industry* compared to *non-grouse shooting groups*, and (b) *Government agencies* compared to *non-government groups* (see Supporting Information). We focused on these two comparisons because there is the possibility that scientists in

TABLE 1 Ecosystem properties considered in the review, and how each property was classified in response to burning

Ecosystem property response to burning	Classification
Sphagnum growth/abundance	+ = positive response (e.g. increased growth and/or higher abundance/cover suggested) − = negative response (e.g. decreased growth and/or lower abundance/cover suggested) 0 = no or mixed response suggested
Mean and/or maximum soil temperature	+ = decreased temperatures suggested − = increased temperatures suggested 0 = no temperature change
Peat exposure and/or erosion	+ = reduced bare peat and/or erosion − = enhanced bare peat and/or erosion 0 = no or mixed response
Aquatic invertebrate communities	+ = positive response suggested (e.g. higher diversity and/or densities of sensitive taxa) − = negative response suggested (e.g. lower diversity and/or densities of sensitive taxa) 0 = no or mixed responses
Peat physical and/or chemical properties (including pore water chemistry)	Yes = some change suggested No = no change suggested
Stream chemistry	Yes = some change suggested No = no change suggested
Peatland hydrological function	Yes = some change suggested No = no change suggested

receipt of such funding can find themselves drawn to present, or at least highlight, certain conclusions that are to the satisfaction of either group of funders, thus rendering further funding from the same source more likely. Studies where no funding information was provided were allocated to non-grouse shooting groups, and non-government groups, for the two analyses. Fisher's exact test for count data was used to test associations between sponsor groups and research conclusions.

3 | RESULTS

3.1 | Examination of A&H claims

A&H suggested EMBER results are unreliable because they were based on a space-for-time approach with treatments located in geographically separate and environmentally distinct sites. A&H further implied this was not accounted for during data analysis. The basis of this criticism is unclear because: (a) analyses did examine numerous site-specific variables and differences; (b) EMBER included experimental manipulations, so it was not solely space-for-time (e.g. Aspray et al., 2017; Brown et al., 2019); (c) when other authors have pointed out problems with their analyses (Evans et al., 2019), A&H defended using geographically separate study sites to justify their own research on moorland burning because 'sampling across a wider area with climatic differences should be seen as an advantage, as it offers real and meaningful replication rather than providing detailed records for only one site' (Heinemeyer, Burn, Asena, Jones, & Ashby, 2019, p. 2).

A&H suggested slope varied between EMBER plots, but they made a fundamental mistake in their assessment of how EMBER incorporated slope. Three soil papers (Brown et al., 2015; Holden et al., 2014, 2015) stated that plot locations were determined based on topographic index (TI) categories. Consequently, across the catchments, there were three groups of plot locations defined by the TI which incorporates both slope angle and upslope drainage length, which is a much more logical approach for comparing treatment effects than just using slope angle (Anderson, Goodale, Groffman, & Walter, 2014; Beven & Kirkby, 1979; Holden, 2005; Zinko, Seibert, Dynesius, & Nilsson, 2005). As expected, when separately grouped by burn age category within each catchment, topslope positions most frequently had the deepest median water tables, while footslope positions most frequently had the shallowest median water tables (Figure 1). Unfortunately, many blanket peatland management impact studies (e.g. Heinemeyer et al., 2018; Lee, Alday, Rose, O'Reilly, & Marrs, 2013) have neglected to recognize or factor-in TI as part of their designs making interpretation of their findings difficult.

A&H used a 50 × 50 m digital elevation model covering each of the EMBER plots and suggested a significant difference in slope between unburnt (steeper) and burnt plots. However, their analysis suggests that the difference was <1°, which is so small in the context of UK moorlands that their criticism has no physical implications

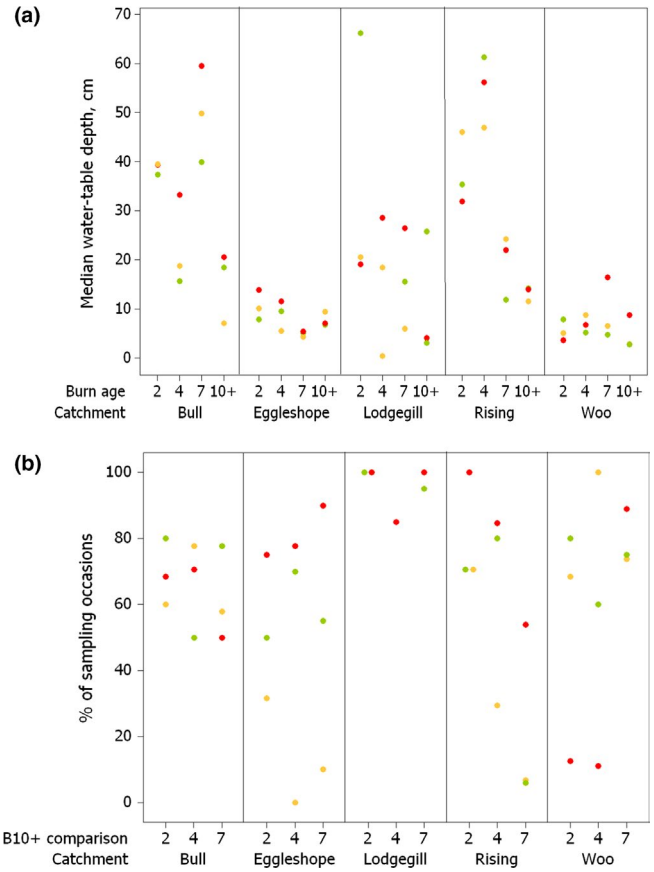

FIGURE 1 Within-site water-table comparisons for 'Effects of Moorland Burning on the Ecohydrology of River basins' burned catchments: (a) median water-table depth per plot; (b) % manual dipwell sampling occasions that water-table depth in a plot burned >10 years prior to measurement was shallower than in plots 2, 4 and 7 years since burn. Data were only compared within catchments for plots with the same slope position. Red = topslope, amber = midslope, green = footslope. At Lodgegill Sike, there were 2× burn age = 4 years midslope plots and 2× B10+ footslope plots, and no B4 footslope or B10+ midslope plots

and so can be disregarded. First, given that EMBER plots were approximately 20 × 20 m, 1° lies well within the margin for error when calculating slope using a 50 × 50 m UK upland grid. Second, A&H did not show how this effect size could possibly be meaningful, particularly as blanket peatland is often found covering slopes up to 20° (Lindsay et al., 1988) and in extreme cases up to 30° (Ingram, 1967). Third, in theory, steeper plots have a greater likelihood of deeper mean water-table depths with more variability than less steep plots. However, Holden et al. (2015) reported burnt plots had significantly deeper mean water-table depths and greater water-table variability than unburnt ones. This is the opposite of what A&H's slope analysis suggests. A similar point can be made about the potential effects of slope that A&H hint at (although they do not explain what these could be) for the macropore flow and hydraulic conductivity study by Holden et al. (2014). Holden (2009) established that more gentle peat slopes are associated with higher macropore flow and saturated hydraulic conductivity. In contrast, Holden et al. (2014)

showed that plots subject to recent fire (prescribed or wildfire) had lowest macropore flow and saturated hydraulic conductivity, no matter whether they were on less steep, equal or steeper slopes than other treatments. Holden et al. (2014) showed this finding was significant within site (e.g. comparing B2, B4 and B15+ plots at Bull Clough: ANOVA % macropore flow $p < 0.001$ ($F = 10.8$) for burn age, $p = 0.114$ ($F = 2.3$) for slope position; log saturated hydraulic conductivity $p < 0.001$ ($F = 16.7$) for burn age, $p = 0.187$ ($F = 1.7$) for slope). Hence, this additional evidence indicates that the effects of burning were sufficiently large to override slope effects encountered within EMBER plots.

A&H questioned whether EMBER plots (by burn age or burned/unburned) were distributed equitably by aspect, although in their own analysis, they did not find any significant effect. A&H noted that 'elevation exerts a strong influence on precipitation which, in turn, affects peatland water tables and overland flow'. By inference, they suggested that hydrological data from the EMBER sites are therefore problematic as catchments were (unavoidably) in different locations. However, their own analysis (Figure 2c in A&H) showed no significant overall difference in elevation between burnt and unburnt catchments. Furthermore, analysis of data in A&H's Table 2 reveals two significant weaknesses in their argument: (a) there was no significant relationship between mean elevation and mean monthly precipitation ($R^2 = 0.19$, $p = 0.21$), or when using catchment outlet elevation ($R^2 = 0.11$ $p = 0.36$); (b) A&H presented the same precipitation values for two catchments in burned and unburned categories, with no explanation of the errors that underpin this issue and thus their analysis overall. With only $n = 4$ rainfall totals, and using ANOVA as per A&H, Figure 2b in A&H's paper becomes $p = 0.07$, $R^2 = 0.45$. While part of Holden et al. (2015) could be criticized for using combined flow data across storms and sites, datasets are not extensive enough for the analysis of multiple covariables. A&H, however, neglected the fact that Holden et al. (2015) clearly accounted for possible between-catchment rainfall effects in their analysis of storm event responses and provided a site-by-site breakdown of results (e.g. Tables 3 and 4 within Holden et al., 2015). For example, *for every catchment*, a sample of rainfall events that was recorded within that specific catchment was selected for analysis and average storm-response results for each catchment were presented. A separate empirical study by Grayson, Holden, and Rose (2010) assessing a long-term discharge dataset with changing vegetation cover conditions across a UK blanket peat-covered catchment suggested that vegetation removal that exposes peat could alter river run-off responses in line with EMBER results. Given the wider limitations of existing discharge data from UK upland peatland sites, hydrological models that test scenarios of vegetation removal, based on physical understanding from multiple studies across different sites, provide further insights to catchment hydrology responses to burning. For example, Gao, Holden, and Kirkby (2016) showed that exposure of peat could alter river run-off responses in line with EMBER results.

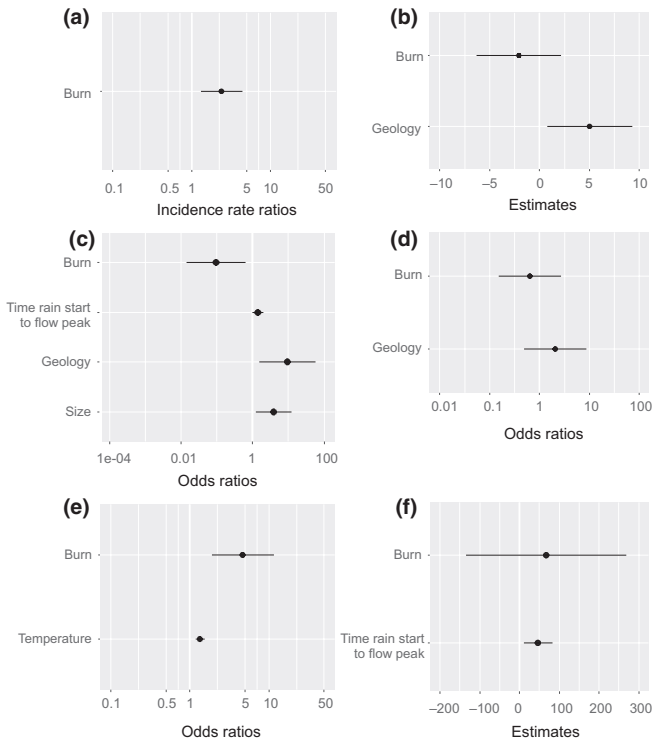

FIGURE 2 Effect size plots for river ecosystem measures considered to be affected by burning in Brown et al. (2013): (a) FPOM density, (b) taxonomic richness, (c) % ephemeroptera, (d) Simpson's diversity, (e) % chironomidae, (f) total invertebrate density. See Supporting Information for summary statistics

TABLE 2 Correlation statistics for mean flow variables (Holden et al., 2015) and the non-metric multidimensional scaling solution in Brown et al. (2013). Two variables that correlated significantly (shown in italics) were not associated with altitude or catchment size (Figure S1)

Variable	R^2	p
Time start of rain to peak flow	0.006	0.88
Time peak rain to peak flow	*0.13*	*0.04*
Rainfall before rise in river stage	0.06	0.25
Rainfall before steep rise in hydrograph	0.002	0.96
Recession time	*0.29*	*0.002*

The EMBER design enabled detailed comparison of recent burns to mature heather plots within catchments. This offers further evidence for burn effects since rainfall or altitude differences across study plots within each catchment would be small, and these findings support our previous conclusions where analyses had utilized combined datasets. Effects of time since burn on water-table depth are evident for the five burned catchments (Figure 1a). Using water-table data from burned catchments, the effect size for within-catchment differences is generally large (Figure 1b). For 33/41 paired plot comparisons, water tables were shallower in B10+ plots (burned >10 years prior to measurement) compared to plots burned more recently and for the same slope position. For 25 of these paired plot comparisons, water-table depth was shallower for B10+ plots on >2/3 sampling occasions (Figure 1b). In Brown et al. (2015),

Slope position	B7+	B4	B2
Topslope			
Original	0.63 ± 2.37* [0.15]	1.88 ± 3.65*** [0.35]	2.77 ± 4.49*** [0.42]
Re-analysis	0.09 ± 1.65* [0.17]	1.09 ± 2.72*** [0.38]	1.78 ± 3.36*** [0.45]
Midslope			
Original	−0.21 ± 1.99	1.46 ± 3.50*** [0.26]	1.04 ± 2.44*** [0.26]
Re-analysis	−0.57 ± 1.74	0.65 ± 2.53*** [0.28]	0.55 ± 1.95*** [0.29]
Footslope			
Original	0.89 ± 3.46* [0.12]	0.30 ± 2.65	2.27 ± 4.66*** [0.31]
Re-analysis	0.09 ± 2.42* [0.11]	−0.31 ± 1.81	1.17 ± 3.13*** [0.32]

TABLE 3 Mean ± 1 *SD* $\hat{u}_t$ estimates for odd-day maximum daily temperature predictions at the soil surface, with significance results from *K-S* tests for each EMBER age plot (B7+, B4 and B2 = plots burned >7, 4 or 2 years prior to measurement) relative to B15+ plots [*$p < 0.05$; **$p < 0.01$; ***$p < 0.001$]. Values in square parentheses are Cliff's δ estimates of effect size. See Brown et al. (2015) for original data analysis

TABLE 4 Summary review statistics for ecosystem properties relevant to 'Effects of Moorland Burning on the Ecohydrology of River basins' (EMBER) papers. Parentheses exclude two EMBER sedimentation experiment papers

Ecosystem property response to burning	Relevant papers	Studies suggesting positive change	Studies suggesting negative change	Studies suggesting no or mixed response
Sphagnum growth/abundance	20	6	5	9
Mean and/or maximum soil temperature	3	0	3	0
Peat exposure and/or erosion	8	0	8	0
Aquatic invertebrate communities	5 (3)	0	5 (3)	0
Combined findings	35 (33)	6	20 (18)	9

Ecosystem property response to burning	Relevant papers	Studies suggesting change	Studies suggesting no change
Peat physical and/or chemical properties (including pore water chemistry)	24	22	2
Stream chemistry	12 (10)	10 (8)	2
Peatland hydrological function	9	9	0

differences between plots located within the same site were reported for soil temperatures, again with the clearest responses for those burned most recently.

Although A&H argued that EMBER did not control for site effects, they noted that, when examining the association between environmental variables and vegetation (Noble et al., 2018), site was incorporated as a factor within models. It is not at all clear why A&H decided Noble et al. (2018) '*was not associated with the main EMBER project*'; the acknowledgements of the paper cite the grant funding, three authors were from the EMBER team and the paper investigated EMBER plots. Importantly, Noble et al. (2018, p. 565) already showed that '*geographically variable vegetation community characteristics can be overridden by the effects of burning*'.

A&H criticized Brown et al. (2013) for not considering any between-site differences when analysing macroinvertebrate community and river habitat responses to burning. The suggestion by A&H is inaccurate because the analysis did include water temperature data, which were associated with altitude ($R^2 = 0.56$, $p = 0.013$). Analyses already detailed in that paper showed water temperature was not associated with the NMDS solution, nor was catchment size ($R^2 = 0.04$; $p = 0.365$). Rainfall was not incorporated into this analysis because rainfall–run-off relationships are modified by catchment processes, and river invertebrates would thus respond to flow rather than rainfall. Incorporation of mean flow metrics subsequently provided for each catchment by Holden et al. (2015) suggests that invertebrate communities may be associated with flow variability in our study (Table 2) including changes linked with vegetation burning. Additional analysis suggests these site variables were not associated with communities in five time periods (i.e. excluding spring 2010, for which environmental data were unavailable in full), but three periods showed an effect of burning (ANOSIM Period 2: $R = 0.16$, $p = 0.1$; Period 3: $R = 0$, $p = 1.0$; Period 4: $R = 0.44$, $p = 0.013$; Period 5: $R = 0.35$, $p = 0.033$; Period 6: $R = 0.325$, $p = 0.046$).

Additional analysis incorporating site-level covariates confirms a strong association between burning and riverbed FPOM densities (Figure 2, Supporting Information), and no clear association with geographic covariables. Effect size estimates suggest burning typically enhances FPOM density by 2.4× (95% range −0.3 to 5.1). For individual rivers, FPOM density >5 g/m^2 was evident across burned rivers for 11/25 samples, with two densities >100 g/m^2. In contrast, density >5 g/m^2 was observed for only 2/23 samples in unburned rivers, despite the same random sampling method being used consistently. Incorporation of geographic covariables still suggested burn effects on river macroinvertebrate communities (Figure 2) and in agreement

with conclusions of Brown et al. (2013). EMBER experimental evidence (Aspray et al., 2017; Brown et al., 2019) directly implicated peat sediment FPOM deposition as a driver of river macroinvertebrate community changes. A key question arising from these findings is where could the extra sediment in rivers draining burned catchments come from?

Vegetation removal with fire often exposes the peat surface, enhancing erosion potential, possibly through micro-rill development around exposed tussocks and other microforms (e.g. Lindsay, 2010), with sediment transfer to rivers then more likely. This erosion risk is recognized explicitly in the Heather & Grass Burning Code (Defra, 2007) and the Scottish Muirburn Code (Scottish Natural Heritage, 2017), both produced in close consultation with groups that advocate burning. Both codes advise against burning within 5 m of watercourses, with the Scottish code suggesting this can be reduced to 2 m depending on watercourse width. Despite this clear guidance, aerial imagery (2009) for five burned EMBER catchments highlights burn areas alongside and even directly over watercourses (Figure 3). Similar examples can be observed on many other moors via Google Earth, and from ground-level photography (Figure S3). Eroded peat from patches burned close to watercourses could therefore be transported easily into headwater rivers. Aquatic ecosystem effects can occur quickly over hours–days after deposition of acute sediment pulses (Aspray et al., 2017), while in burned peatland rivers, sediment deposition is also likely to be a chronic stressor. Burning adjacent to watercourses was not considered in a previous assessment, which suggested that prescribed burning on one selected moor followed the Defra code best practice (Allen, Denelle, Sánchez Ruiz, Santana, & Marrs, 2016). We contend that the wider extent of this problem needs to be quantified from further aerial imagery and ground-based assessments to measure compliance with voluntary burning codes.

A&H proposed that some soil surface temperatures measured in EMBER plots could be due to measurement error caused by sensors at the peat surface having parts exposed to sunlight. While Brown et al. (2015) used the term 'surface' for sensors placed shallowest in the soil profile, they also explained that sensors were placed horizontally in the top 1 cm of the peat-litter layer (i.e. not directly on the surface) and checked every 3 weeks. Some maximum temperatures recorded at B2 plots were similar to those reported by Kettridge, Thompson, and Waddington (2012) for Canadian peatlands after fire, even though they used a different sensor (see discussion in Brown et al., 2015). We therefore have confidence in the temperature data from our study. Several lines of evidence, including some available to A&H, provide further evidence-based assurance that the EMBER soil temperature data are robust: (a) higher temperatures were recorded with sensors buried at 5 cm depth in B2 plots (Brown et al., 2015) and surface temperatures at these locations would have been similar to/higher than 5 cm depth; (b) sensor exposure to sunlight cannot explain why the lowest temperatures were also recorded in recent burn plots, which in turn would enhance soil ice formation and erosion processes (Li, Holden, & Grayson, 2018); (c) further analysis of data with the top 10% disturbance values removed confirm findings in Brown et al. (2015; Table 3). Notably, removal of the highest temperatures increased the effect size for 6/7 burned plots where there was a statistically significant temperature increase compared to B15+ plots (plots last burned >15 years ago). Thus, even after exclusion of the most extreme temperature measurements from the EMBER dataset, vegetation removal with fire can be expected to increase maximum soil temperatures in the years that follow. In addition, studies in other peat soil types following vegetation burning have suggested higher temperatures at 2 cm depth (Grau-Andrés, Gray, Davies, Scott, & Waldron, 2019). Obvious

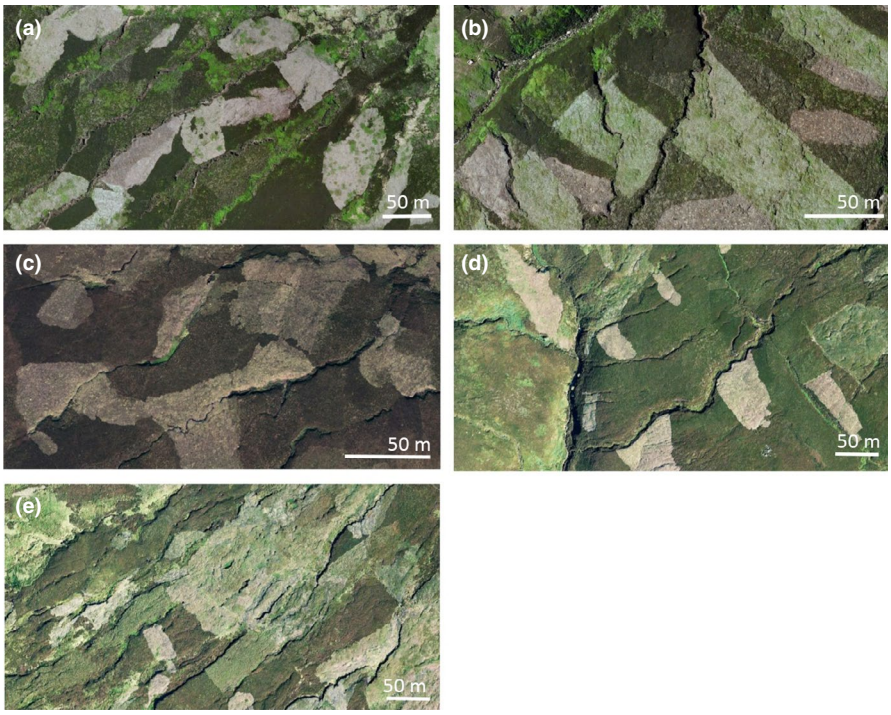

FIGURE 3 Recently burned areas (light colour patches) adjacent to, and crossing, watercourses in 'Effects of Moorland Burning on the Ecohydrology of River basins' catchments: (a) Rising Clough (31/05/09, 53°23′55.76″N, 1°41′23.04″W), (b) Bull Clough (31/05/09, 53°28′19.31″N, 1°42′51.49″W), (c) Woo Gill (10/04/09, 54°12′13.42″N, 1°54′12.38″W), (d) Great Eggleshope Beck (09/12/09, 54°41′8.07″N, 2°4′1.64″W), (e) Lodgegill Sike (09/12/09, 54°40′28.97″N, 2°4′15.91″W). Imagery from Google Earth, © 2019 Infoterra Ltd & Bluesky

TABLE 5 Fisher's test results for grouse-shooting industry and government-agency funded projects, versus those funded by other groups. For the three categories with a single comparison, pairwise test values could not be computed (n/a). *p*-values = 1 except where stated. Italics indicate significant values

Funding/Ecosystem property	Overall test	Positive: no-effect	Positive: negative	No-effect: negative
Grouse-shooting industry				
Sphagnum growth/abundance	*0.0088*	0.12	*0.045*	
Soil temperature				
Bare peat/erosion				
Aquatic invertebrates				
Hydrological function		n/a	n/a	n/a
Stream chemistry		n/a	n/a	n/a
Peat physical/chemical properties	0.4368	n/a	n/a	n/a
Combined effect	*0.00053*	0.1217	*0.001577*	0.6601
Government agencies				
Sphagnum growth/abundance	0.8483			
Soil temperature				
Bare peat/erosion				
Aquatic invertebrates				
Hydrological function		n/a	n/a	n/a
Stream chemistry		n/a	n/a	n/a
Peat physical/chemical properties	0.302	n/a	n/a	n/a
Combined effect	0.464			

drivers of soil thermal changes are the removal of shrubs, which would change insulation, shading and soil hydrology.

3.2 | Review to contextualize EMBER findings

The ecosystem properties with the largest number of papers relevant to EMBER findings were those concerned with alterations to soil physical and chemical properties, and to *Sphagnum* growth/abundance (Table 4). Whilst total numbers are small for some categories, four properties appear to show a response to burning that is consistent with the findings of EMBER: (a) mean and/or maximum soil temperatures increase following prescribed burning, (b) exposure of the peat surface and/or more erosion, (c) alteration to catchment hydrological functions and (d) aquatic invertebrate community change. The latter applies even if our two papers (Aspray et al., 2017; Brown et al., 2019) on sedimentation stressors associated with burning are omitted, although studies in this category have only been undertaken by ourselves. Similar findings for temperature and soil exposure/erosion have been reported from studies on other organic soils following burning (Grau-Andrés et al., 2019). A majority of the available studies have reported some form of alteration to soil physical and/or chemical properties, as well as to stream chemistry, following prescribed burning. Our analysis suggests that the most variable or even contradictory conclusions arise from *Sphagnum* growth/abundance studies. Overall, we found a combined findings effect of burning for the first four properties listed in Table 4, with >3 times more studies having suggested 'negative' effects on

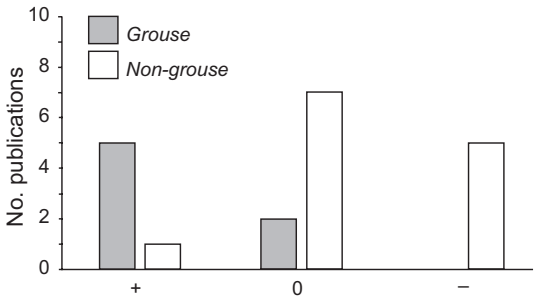

FIGURE 4 *Sphagnum* growth/abundance publications in +/0/− categories for grouse shooting industry and non-grouse shooting groups

the environment following moorland vegetation burning compared with studies that suggested 'positive' effects. Even when compared against studies that suggested no or mixed effects, there were more studies suggesting 'negative' effects.

3.3 | Sponsor identity

Of the 68 papers reviewed, 11 had declared funding links to grouse shooting groups and 30 cited government agency funding. While there were no apparent statistical links between government agency funding and suggested burn impacts, for studies funded by the grouse shooting industry, there was a significantly higher probability of suggesting positive effects of burning for *Sphagnum* growth/abundance and the combined findings (Table 5). For *Sphagnum*

growth/abundance, a marked divergence in suggested responses was associated with sponsor identity (Figure 4). Most of the + publications are based on data from a single experimental area on sloping blanket bog at Moor House, northern England.

4 | DISCUSSION

Sponsorship effects are a known phenomenon in science (Lesser, Ebbeling, Goozner, Wypij, & Ludwig, 2007), although this is not necessarily problematic if researchers are transparent about their reasons for undertaking a piece of research. Our analysis suggested that sponsor identity was associated only with grouse shooting industry funded work and not with government agency funded studies. This is despite the obvious potential for effects to occur both ways. We do not suggest that these effects are deliberate: it is possible that they can arise unconsciously at any stage of a project, and/or the effect could reflect the grouse industry sponsored studies mainly being undertaken in a restricted geographical area. Sponsors should, however, be considered when policymakers evaluate scientific evidence for translation into policy, and there should be cause for concern if researchers are not fully transparent about funding sources or potential conflicts of interest both when publishing research and/or when undertaking peer review.

Given the above findings, some concerns arise in relation to moorland vegetation burning publications where funding and potential conflicts of interest were not declared in the original publication (e.g. Ashby & Heinemeyer, 2019; Heinemeyer et al., 2018; Marrs et al., 2019b). In the case of A&H this is despite the announcement in 2017 by the British Association for Shooting and Conservation (BASC) of a 5-year funding award of £25,000 to Heinemeyer. BASC is a gun sports association that promotes the management of heather on grouse moors, including on peatlands, through controlled burning. These funding links were clearly documented online (https://basc.org.uk/basc-backs-moorland-study/, accessed 10/02/2020) and in Shooting Times (14/6/2017, p. 7) almost 2 years before the A&H paper was first submitted. While Heinemeyer has received funding for his work from multiple sources, BASC's funding announcement was notable for the inclusion of two clear statements questioning EMBER results. Funding from BASC or any other organization that encourages the use of controlled burning as a tool for managing heather on grouse moors of course does not disqualify authors from criticizing other research studies. It is, however, not clear why A&H did not list perceived conflicts of interest so that editors, reviewers and subsequent readers would be able to take a fully informed view of their EMBER critique. The acknowledgements states that the UK Natural Environment Research Council (NERC) funded the work presented in the EMBER critique paper. However, UK PopNet (2006–2010) and NERC centre F14/G6/105 (2002–2012) grants appear to have ended before any EMBER paper was even published. Thus, it is unclear how these NERC projects could have funded the A&H critical analysis. We accept that the above discrepancies may have been unintended or there could be valid explanations, but due care is required by scientists when they submit papers to academic journals for peer review to ensure potential perceived conflicts of interest can be managed by the editorial process.

We have shown that: (a) geographical variability does not confound EMBER conclusions about burning effects on peatlands; (b) EMBER soil temperature findings are robust and (c) EMBER project findings are broadly in line with the majority of other published studies on similar variables impacted by prescribed burning. Several assertions and cautionary statements made by A&H about the EMBER project have been shown to be unfounded. Sponsor effects on all studies both supporting or rejecting the continued use of managed burning need to be considered by UK policymakers, in the same way that conflicts of interest are openly considered in other sociopolitical situations. Formal meta-analysis would provide an alternative way to evaluate any potential bias in comparison to our study-count approach, but researchers will routinely need to provide clearly defined and comparable effect size estimates to enable these kinds of analyses. We agree with A&H that policymakers need sound evidence to support the policy process on moorland burning. Fully transparent statements about funding and potential conflicts of interest, supplied at the outset of the peer review and publication process, represent a key part of the assurance that published research is reported and reviewed as objectively as possible. Any apparent weakening of this principle should be a source of concern to all who publish.

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AUTHORS' CONTRIBUTIONS

Both authors conceived the ideas and designed methodology; both authors collected the data; both authors analysed the data; both authors led the writing of the manuscript and gave final approval for publication.

DATA AVAILABILITY STATEMENT

Data available via University of Leeds Repository https://doi.org/10.5518/833 (Brown & Holden, 2020).

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SUPPORTING INFORMATION

Additional supporting information may be found online in the Supporting Information section.

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