An outline summary document of the current knowledge about prescribed vegetation burning impacts on ecosystem services compared to alternative mowing or no management

Andreas Heinemeyer (SEI-York) & Mark Ashby (Whitebeam Ecology)

Introduction

Despite substantial contrary evidence, there has been a growing tendency to present prescribed burning as a management practice that is only ever damaging to peatland ecosystems in the UK (Thompson et al. 2016; Natural England 2019; Wild Justice 2019). This is exemplified by the recently released "*Burning and Peatlands*" position statement by the IUCN UK Peatland Programme (IUCN 2020). Indeed, while we strongly agree with several of the statements made within this position statement, it also contains a series of unverified assertions and misleading arguments that serve to simplify the narrative and paint prescribed burning as a peatland management tool that is only ever damaging. Given that this position statement is published by one of the UK's most prominent peatland conservation organisations, it is likely to be consulted when debating and designing upland land use policy. Therefore, for the benefit of policymakers, we provided a point-by-point critical review of the "Burning and Peatlands" position statement (Ashby & Heinemeyer, 2021). We also discuss several further points that should be considered by practitioners and policymakers when inferring the impact of prescribed burning.

We are neither pro nor anti burning; our aim in producing this summary document is to encourage robust research and evidence assessments and support the practitioner and policy community to move towards an evidence-based position about management impacts on UK upland peatlands, which considers burning as part of several options that can be deployed depending on site conditions and context (i.e. the right tool in the right place for the right reason). Given the uncertainties within the evidence base and practicalities of conducting robust experimental research, we suggest land managers follow an adaptive management approach when using prescribed burning. The fundamental tenet of adaptive management is to monitor management interventions and use the results to inform future actions (e.g. by halting any interventions that are found to be damaging) (Holling 1978). We propose that a 'learning by doing' approach should be endorsed within grouse moor management policy because it (i) allows various managements to continue as long as landowners monitor the environmental impacts of their interventions (ideally supported by scientific input at representative high-intensity monitoring sites); (ii) encourages landowners to adopt a more cautious approach to management (by realising the benefits and challenges of different options); (iii) potentially ensures more environmentally sensitive management techniques are trailed and tested (before being adopted in general); and, (iv) contributes to evidence base (in a real-world context).

Before a more detailed summary about common assertions, we would like to highlight three main points to be considered when considering any decision regarding (prescribed burn) management:

1) To date, no study has assessed prescribed burning impacts using a real-world approach, with measurements made across active grouse moors and extending over a **complete management cycle**. Thus, the current evidence base cannot be used to draw robust conclusions about ecosystem services impacts, particularly in relation to carbon storage, GHG emissions, flooding and water quality.

2) The results of many burning studies are unreliable because they use **experimental designs** that are unable to detect causal or generic relationships and/or make significant statistical errors. We suggest that the entire evidence base needs to be reviewed on this basis. Indeed, this is crucial to obtain robust evidence on which to base policy.

3) Due to the uncertainties within the evidence base, the **precautionary principle** is often cited as a reason to halt prescribed burning on peatlands. However, it is rarely (if ever) applied when considering other even more understudied/unproven peatland management options (e.g. mowing/cutting of heather or no management, as well as restoration measures like rewetting, are also likely to cause negative impacts when applied in certain contexts). It should not be used as a basis for decision-making (Peterson 2007).

The following contains common assertions followed by our response (in relation to blanket bog):

1. **Burning is damaging to peatlands (functioning bog)**

   There is no consensus within the literature that prescribed vegetation burning is damaging to peatlands. Several recent reviews and commentary papers demonstrate that the overall effect of burning on peatlands is unclear due to insufficient, contradictory or unreliable evidence on carbon, water quality and biodiversity (Davies et al. 2016b; Harper et al. 2018; Ashby and Heinemeyer 2019). Moreover, damage such as bare ground is short-lived (only a few years) and small scale (usually <10% cover within quadrats), which is often ignored in assessments. Finally, flooding impacts are mostly linked to reduced runoff from unrelated studies on re-vegetation of bare/eroding peatlands, not a patchwork of vegetated prescribed burn areas, and the huge C emissions that are often reported for degraded peatlands are largely based on lowland arable peatlands (by far the biggest peatland C source). Notably, the emissions inventory currently does not include any net GHG data for grouse moors.

2. **Peat-forming species and specific indicators (*Sphagnum* moss species)**

   Burnt areas can support similar levels of *Sphagnum* and *Eriophorum* spp. (purported 'peat-forming' plant species) to comparable unburnt or not recently burnt areas (e.g. Lee et al. 2013a; Milligan et al. 2018; Noble et al. 2018a,b; Whitehead and Baines 2018; Grau-Andrés et al. 2019a). Notably, the 'peat-forming' label is not supported by any robust experimental evidence (i.e. peat core evidence cannot be used for this), which also applies to the claim of unique "peat-forming" capabilities of *Sphagnum* moss (see Bacon et al., 2017). It is foremost the environmental conditions that regulate peat formation, namely hydrology (waterlogged), then pH (acidic) and litter quality (e.g. lignin content) and other factors (e.g. redox potential). A review published by Natural England clearly states that any plant species (including heather) can form peat in the right conditions (Shepherd et al. 2013; Gillingham et al. 2016). Finally, individual *Sphagnum* species may not be the most sensitive habitat indicators because i) of their wide environmental tolerances (c.f. Plates 1i - 1viii in Daniels and Eddy 1985); and, ii) we lack mechanistic data on their contribution to important peatland functions (e.g. peat and carbon accumulation).

3. **Burning promotes drier communities (confounding effects deep drainage)**

   It is important to disentangle the impacts of burning from the impacts of drainage, as the latter is often overlooked or intentionally confused with the former (e.g. Young et al. 2019). In general, burning was historically associated with drainage (i.e. 1970s). Thus, where there has been a shift to drier communities, it is likely to be due to the lowering of water tables induced by drainage rather than prescribed burning. Notably, slight surface drying by heather provides a thin non-saturated (i.e., aerobic) layer favourable to methane oxidation (Roslev and King, 1996). Deep drainage clearly has negative impacts on key peatland functions such as carbon storage (e.g. Young et al. 2019). But when commenting specifically on vegetation burning, we must consider burning in isolation, especially as many remaining drainage ditches are now actively blocked or have naturally infilled over time. Moreover, claims of increased "micro-erosion networks" and "increased tussock formation" due to burning are scant and highly speculative, are seemingly based on only one study in the North Pennines (Clutterbuck et al. 2020), and are never linked to actual impacts on ecosystem functions (e.g. hydrology). Much hotter and more severe wildfires that burn into the peat can dramatically alter vegetation, such as increase *Molinia* grass on wet heath and acid grassland, but this should not be confused with the impacts of prescribed heather burning on deep peat with high water tables (as it has been in some documents, e.g. Tucker 2003).

4. **Rewetting impacts – natural state (flood risk, GHG emissions & wildfire prevention)**

   There is little evidence that peatlands in their 'natural' state only ever provide ecological and environmental benefits. When rain falls on a saturated peatland, the rainwater will either pond and partially drain on flat areas or, on slopes, runoff (Holden and Burt 2003; Acreman and Holden 2013). There is a limit to peat wetness; the latter process is called saturated overland flow, which can increase the volume and possibly the speed of water running downhill into river catchments from areas of saturated upland peatland (e.g. Holden and Burt 2003). Thus, a rewetted and saturated upland peatland could exacerbate rather than mitigate downstream flooding (Acreman and Holden 2013). Peatland rewetting may also have a negative impact on climate change mitigation because peatlands with high water tables also emit large amounts of methane, particularly if combined with increasing temperatures (Abdalla et al. 2016), with methane having a much greater global warming potential (GWP) than carbon dioxide. This issue has been highlighted by both short-term and long-term assessments of peatland methane emissions (Cooper et al. 2014; Vanselow-Algan et al. 2015). However, there is a negative relationship between site wetness (soil and vegetation moisture) and burn damage to the moss, litter and peat layers (Taylor 2015; Grau-Andrés et al. 2017; Grau-Andrés et al. 2018; Grau-Andrés et al. 2019a).

5. **Habitat state of peatlands – favourable vs unfavourable condition (degraded, modified, intact state)**

   So far, habitat status is based on vegetation composition, using arbitrary pass-fail criteria that do not measure actual ecosystem parameters and functions. Importantly, plant traits are poor indicators for defining ecosystem functions (von der Plas, 2020). Criteria should thus be based on ecosystem functions & ecosystem services – underpinned by robust empirical measurements of peat accumulation, water storage and other important ecosystem services, such as water quality. Whilst the majority of blanket bogs in SACs (59%) are actually on a positive ecological trajectory (i.e. bogs that are 'Favourable' or 'Unfavourable-recovering') (JNCC 2006), it seems that bogs currently classed as unfavourable (i.e. degraded) could actually be in good ecological condition (and vice versa), that is, they have water tables at or near the bog surface and are actively accumulating peat (Heinemeyer et al. 2019c). However, conflicting outcomes should be expected for different ecosystem services under different land management scenarios (e.g. Bennett et al. 2009; Power 2010). For example, a permanently saturated peatland (i.e. a peatland with a water table at or above the peat surface) could be expected to have a lower catchment flood mitigation potential and a net positive greenhouse gas (GHG) budget via higher methane emissions.

6. **Prescribed 'cool' burning (biomass charcoal) vs uncontrolled 'hot' burns (peat combustion)**
A range of British studies show that the moss and peat layer within (wet) blanket bog ecosystems are generally buffered from the effects of a 'cool' prescribed burn (i.e. minimal moss damage and no peat ignition) (Grau-Andrés et al. 2017; Grau-Andrés et al. 2018; Grau-Andrés et al. 2019a; Grau-Andrés et al. 2019b). Crucially, about 5-10% (more if including charred sticks) of biomass C is converted into a long-term carbon store, charcoal (Heinemeyer et al. 2018). Conversely, mowing will allow nearly all biomass to decompose over time, likely only locking away less than 5% of biomass C as peat. Finally, uncontrolled and 'hot' wildfires likely burn into the peat layer and tend to occur during the summer months (Albertson et al. 2009). Even though wildfires occur much less frequently than prescribed burns, owing to their size and severity, they lead to far greater losses of C, including from peat. Finally, any assessment of burning impacts on carbon / GHG emissions must also consider methane fluxes, especially given the recent evidence that suggests low-severity fires may suppress peatland methane emissions (Davidson et al. 2019; Gray et al. 2020) and mowing or unmanaged sites might emit far more methane (Heinemeyer et al. 2019c).

7. **Burning of peat after rewetting and under uncontrolled hot burns**
Despite what is often claimed, the wildfire mitigation potential of peatland rewetting has never been tested within a UK context. There are two aspects to wildfire mitigation: ignition prevention and damage limitation. Firstly, it seems intuitive that wetter bogs would be less likely to ignite (Davies and Legg 2011). However, in summer, bog vegetation becomes very dry, especially during prolonged dry spells. As the vegetation becomes drier, it becomes more flammable. For example, heather becomes flammable when moisture content drops below 60% (Davies & Legg 2011). Moreover, even on hydrologically near-natural peatlands (i.e. peatlands largely undisturbed by human impacts), the water table draws down by as much as 20-30 cm during the summer months (Labadz et al. 2007; Holden et al. 2011); combined with dry conditions, and higher peat porosity in wetter peat, this is likely to significantly increase the flammability of the normally wet peat during drought conditions (Huang and Rein 2017).

8. **Burning and water storage (flood implications)**
Despite what was recently stated during the House of Lords debate about burning on peatland, Heinemeyer et al. 2019c do not show that burning increases flood peaks. Rather, they merely provide a simple (but non-validated) empirical model prediction comparing burnt to mown catchments (n.b. it did not compare burning to unburnt). Conversely, the slightly lower water tables (about 2-3 cm) in burnt vs mown catchments might offer additional storage under conditions when wet sites are saturated. However, only detailed data analysis and subsequent process-based modelling studies will allow testing such flood-related impacts.

9. **Temporal issues: short-term vs long-term impacts (disturbance vs trajectory)**

To date, no study has fully assessed prescribed burning impacts using a real-world approach, with measurements taken across active grouse moors and extending over a complete management cycle (the Peatland-ES-UK is intended to be the first to do so), but, ideally, several management cycles. In short, this means that the impacts of prescribed burning on UK peatlands (especially on carbon and GHG budgets) remain unknown and have yet to be adequately assessed using the correct spatiotemporal context (see Harper et al., 2018). Furthermore, many studies failed to take pre-burn measurements (e.g. Lee et al. 2013a; Lee et al. 2013b; Alday et al. 2015; Noble et al. 2017; Milligan et al. 2018; Noble et al. 2018a; Noble et al. 2018b; Marrs et al. 2019a; Noble et al. 2019b), and crucial post-burn measurements (such as carbon fluxes) are usually only taken for ≤3 years at the start of a burning intervention (e.g. Grau-Andrés et al. 2018; Grau-Andrés et al. 2017; Grau-Andrés et al. 2019b; Noble et al. 2019a) or during a single year across multiple burn ages (e.g. Lee et al. 2013b; Milligan et al. 2018; Noble et al. 2018a; Noble et al. 2019b). Besides being unrepresentative, the short-term approach used to study prescribed burning impacts is biased towards finding adverse effects; since all forms of habitat disturbance (natural or anthropogenic) cause immediate ecological 'damage' (e.g. via soil disturbance, removal of vegetation and/or physiological damage to plants) irrespective of whether they are beneficial over longer timescales. Furthermore, when negative impacts are reported, they are often for short-term effects or for effects that are so small they may not be ecologically significant (Brown et al. 2015; Noble et al. 2018b; Grau-Andrés et al. 2019b; Noble et al. 2019a; Noble et al. 2019b).

10. **Methodological issues: correlative studies vs controlled experimental and model assessments**

The results of many burning studies are currently unreliable or cannot be generalised because they use experimental designs that are unable to detect causal relationships and/or make significant statistical errors (for a discussion of this issue, especially about the frequently cited EMBER report studies, see Ashby and Heinemeyer 2019). For example, several studies confound burnt and unburnt treatments with site and fail to control for this during data analysis. Thus, observed impacts (i.e. differences) cannot be solely attributed to burning (Allott et al., 2019). Several burning studies also commit pseudoreplication and fail to account for data structure during analysis (Ashby and Heinemeyer 2019). By doing this, such studies artificially inflate treatment-level sample sizes, which means the significance values reported are likely much too low, and results cannot be generalised (Davies and Gray 2015). Please note that a response by two of the EMBER report authors, Brown and Holden (2020), did not adequately address any of these issues. Therefore, until this issue is resolved, the EMBER report studies should not be cited to support the claim that burning has a "*significant adverse impact on peatland biodiversity, carbon emissions, drinking water quality and flood management*", and a much wider evidence base needs to be considered. Finally, the recent criticism of two studies, Heinemeyer et al. (2018) and Marrs et al. (2019a), showing considerable C accumulation under rotational burning, was based on a model by Young et al. (2019), which remains non-validated, unspecified, irrelevant (only deep drainage and not burning impacts), and omits key C storage aspects via charcoal (see pre-print responses by Heinemeyer & Ashby (2021) and Heinemeyer et al. (2021)). In fact, recent studies by Leifeld et al. (2018) and Flanagan et al. (2020) support the findings of Heinemeyer et al. (2018) and Marrs et al. (2019a) that low-severity (i.e. prescribed) fires can result in high soil C accumulation rates in peatlands.

11. **Research needs: Burning (long-term), alternative mowing (impacts), scale (practitioner & policy-relevant)**
Robust experimental research is needed at a broad range of nationally representative sites and/or assessments to validate proxies or tests of ecological functions (e.g. peat accumulation) that can be rapidly applied in the field. Such assessments become increasingly complicated when other confounding management (e.g. drainage or grazing), site conditions (e.g. topography; climate) and additional ecosystem services (e.g. net GHG emissions; water quality; biodiversity) or management comparisons (mowing) are included. Such studies must also adequately address location-specific baseline conditions and control for environmental and ecological differences between treatment plots and study sites (Ashby and Heinemeyer 2019). For example, we urgently need robust catchment-scale experiments to ascertain the flood mitigation potential of peatlands in different hydrological, vegetative and management states (including rewetting impacts). We also desperately need more data about the net GHG budget impacts of peatland management, specifically considering how the impacts of rewetting may vary according to future climate scenarios, such as warmer summers and warmer and wetter winters (Kendon et al. 2019; Met Office 2019). We clearly need to measure prescribed burning and alternative management impacts over the correct timescales (15 and >25 years depending on the climate) to capture plant regrowth and practitioner relevant scales (catchment) to capture landscape impacts. To our knowledge, such a detailed assessment is yet to be done.

12. **Uncertain alternatives: mowing (water quality; methane; sedges; micro-topography; birds) & unmanaged (fire)**
Mowing has been shown to (i) cause damage to the peat surface (micro-topography) but remains understudied, as shown by Heinemeyer et al. (2019a); (ii) shift vegetation towards sedge dominance and an associated increase in methane emissions, causing negative impacts on the GHG balance and deteriorating water quality (Heinemeyer et al. 2019c); (iii) on very wet sites, reduce cranefly emergence, which has associated negative impacts on rare upland bird populations (e.g. their chicks relying on those insects). It is suggested within the IUCN (2020) "Burning and Peatlands" document that: "*Where there is uncertainty around the benefits of burning for peatland restoration, the <u>precautionary principle</u> should be applied and burning avoided*". However, for balance, we suggest that this should also apply to other forms of peatland management that have not undergone a full environmental cost-benefit analysis, such as mowing, rewetting or the cessation of vegetation management. For example, compared to burning, we know even less about the impact of mowing (an alternative to burning) on peatland ecosystem services (e.g. greenhouse gas emissions; carbon storage; water quality, nutrient cycling). Moreover, the small amount of evidence we do have suggests that, by raising water tables, rewetting *could* lead to increased methane emissions, increased saturated overland flow and reduced water quality (e.g. Holden and Burt 2003; Cooper et al. 2014; Vanselow-Algan et al. 2015; Abdalla et al. 2016; Peacock et al. 2018). The IUCN (2020) document also fails to consider the risks of ceasing vegetation management on UK peatlands (e.g. increased wildfire risk from increased biomass) (ibid). Instead, the document repeatedly and without evidence, advocates rewetting as a way of reducing wildfire risk (ibid), although recent UK examples question this (Marsden Moor, Dove Stone Moor, Darwen Moor).

13. **Habitat (ecological) condition vs. ecosystem (ecological) functions**

Excluding species of conservation concern, peatland vegetation is, in one sense, irrelevant – ecosystem functioning is what is important. In the case of peatland, this principally means peat-forming, which is largely driven by hydrological (high water table), environmental (low pH) and climatic (lower temperatures) conditions (Gillingham et al. 2016). Land managers may also want to enhance other ecosystem services (e.g. flood, climate change and wildfire mitigation, water quality or avian biodiversity). However, currently, there is a lack of specific evidence in relation to burning and alternative management in relation to all these factors. There is also widespread support for peatland restoration. However, we need clearly defined habitat conditions and objective restoration goals that are based on ecological function. Once such criteria have been developed, we suggest that scientists and government agencies then work together with land managers and, in the UK context, grouse shooting estates to carefully manage an evidence-based and site-specific transition to alternative management. We advocate using a series of 'champion estates' distributed across the UK (to capture different site conditions) that implement alternative and traditional management using a long-term and moorland-scale experimental/monitoring approach.

14. **Independent assessment of the evidence towards policy advice (informed by an unbiased debate)**

An independent assessment of the prescribed burning evidence should weight conclusions according to an objective assessment of the methodological strength (experimental design & data analysis), with studies being rejected from consideration if unreliable (as with many medical evidence reviews). We also need to properly assess the potential role of prescribed burning in wildfire mitigation. For example, it might not always be possible to restrict access to moorlands (to prevent fires), and it only takes one ignition incident to set off a devastating wildfire across a heather-dominated blanket bog. Moreover, vegetation management in remote and often inaccessible areas might prevent management by machinery (no tracks for large mowing equipment), allowing uncontrolled biomass accumulation (fuel load). We need to consider, assess, and try to predict these risks accurately in relation to different site conditions and land management interventions, including prescribed burning, whilst also identifying areas for excluding certain managements; for example, no burning on steep and thus dry slopes, especially adjacent to watercourses. Finally, we also need to produce a set of ecosystem function thresholds based on actual ecological data and an agreed-upon and evidenced set of definitions concerning habitat states within an applied context (i.e. considering statutory bodies and ecosystem services). This will provide us with a meaningful, robust and transparent methodology for defining and assessing a peatland's 'trajectory of recovery'.

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