Impacts of Burning Management on Peatlands

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## Contents

Summary 3

1. Introduction 4
   1.1 Aims and Scope 4
   1.2 Working Definitions 5

2. Aims of Burning and Current Practice, Drivers of Change 5

3. Status and Trends 6
   3.1 Types of Burning 6
   3.2 Geographical Extent 7
   3.3 Timing of Burning 7
   3.4 Methods of Burning 8

4. Effects on Ecosystem Services and Biodiversity – Rationale and Methodology 9

5. Effects on Ecosystem Services and Biodiversity – Review Results 11
   5.1 Biodiversity 11
   5.2 Hydrology 16
   5.3 Carbon and Greenhouse Gas Balance 18
   5.4 Socio-economic impacts 21

6. Practical tools for monitoring and assessment of managed burning 23

7. Good Practice: Potential for Changing Peatland Management to Improve Delivery of Multiple Benefits 23

8. Potential for Policies to Encourage Good Management Practice 23

9. Missing Data 24

10. Conclusions and Key Messages 27

Acknowledgements 28

References 28
Summary

- In the UK, peatlands support a variety of important habitats and rare or threatened species. Peatlands also provide many key ecosystem services such as water provision, flood management and carbon storage. However, all these ecosystem services are affected to varying degrees by land management and human intervention.

- One regularly practiced management technique on peatlands is managed or prescribed burning. The aim of burning is to remove the older, less productive vegetation and to encourage new growth for livestock grazing and for red grouse (*Lagopus lagopus scotica*) production. Burning also can reduce the fuel load on peatlands which may alter the impact of any successive wildfires. Burning occurs across many regions of the UK and recent estimates suggest that 18% of UK peats are subjected to managed burning.

- This review assessed the current status of managed burning within the UK and collated current and ongoing research results that investigate the effect of burning on ecosystem services. By using a formalised review process that assessed both the magnitude and direction of any burning effect, the review was able to draw together findings from across the published peer-review articles and ‘grey’ literature e.g. government reports, unpublished articles.

- The review noted that managed burning can bring positive and negative effects for a range of ecosystem services. For example, burning has been observed to increase grouse and sheep production; however, burning has also been noted to negatively affect the presence of some flora and fauna species e.g. meadow pipit (*Anthus pratensis*) and some *Sphagnum* species.

- For some ecosystem services the evidence is equivocal, e.g. positive and negative effects have been noted for the impact of managed burning on water quality and concentration of dissolved organic carbon (DOC) in particular.

- This multitude of effects across different habitat types leads to difficulties in creating generalised conclusions for the impact of managed burning.

- **The review can make the following recommendations and has identified the following challenges:**
  - Managed burning may bring benefits for some ecosystem services
  - Managed burning has been shown to bring dis-benefits and so individual stakeholders will have decide what is most important in any particular locality.
  - Further research is required into many aspects of managed burning and this review has highlighted suggested areas for investigation.
  - Many of the results from the literature are based on studies that compare the presence with the absence of burning. Few studies compare styles of burning e.g. size of burn strips, methods of ignition. The review would suggest that this is a key area of research for the benefit of policymakers and practitioners alike.
1. Introduction

The purpose of the IUCN UK Peatland Programme Inquiry is to provide a set of briefings on the consensus on the state of peatlands in the UK and the impact of different activities on the ecosystem. The programme aims to investigate blanket bog quality and develop best practice for restoration and monitoring. This review aims to investigate the impact of burning management on peatlands and to reflect on the variety of ecosystem services that burning affects. Prescribed burning is used worldwide for vegetation management; however, there is concern about its environmental impacts.

The regular burning of peatland habitats\(^1\), for the purposes of vegetation re-growth for livestock or red grouse, has shaped the upland landscapes of the UK for many centuries. Burning alters vegetation composition and structure and may in some circumstances enhance biodiversity but in some circumstances may decrease diversity. Inappropriate burning is cited as a reason for poor condition of conservation sites in these areas (Natural England, 2008). A report on the status of Blanket Bog within SSSI sites in England found that only 11% are in favourable condition (Natural England, pers. comm.). Primary reasons cited for poor condition were overgrazing, inappropriate burning and drainage.

Peatlands support many habitats such as dry heath, wet heath and blanket bog. However, there are many classifications and terminologies that are often used interchangeably sometimes leading to confusion in the literature. For example in the uplands, there are 28 upland feature types that cover the 91 National Vegetation Classification (NVC) types in the uplands. Combined with this the status of the peatland is also another factor that can be added to descriptions. Here favourable and unfavourable have technical definitions based on mandatory attributes in which each habitat must cross a minimum threshold (JNCC, 2009).

There is a presumption against burning on blanket bog (Defra, 2007a), though the practice does occur in these active peat forming areas and is agreed to in some burning management plans. Therefore, this review aims to provide a summary of current data from research into managed burning on peatlands and to provide informed opinion on this current thinking. There are already several comprehensive reviews that address the effects of managed burning on a variety of ecosystem services (Glaves and Haycock, 2005; Shaw et al., 1996; Tucker, 2003) so it is not the place of this review to redo the efforts of those authors, rather to draw together studies that have been published since these major reviews.

By reviewing the questions posed at the end of many of these reviews on the data gaps and the research questions still to be posed, this review will seek update these questions in line with recent research.

1.1 Aims and Scope
This review will concentrate on in the impact of burning on four main topics:
- Biodiversity
- Hydrology
- Carbon and greenhouse gas balance
- Socio-economic impacts

\(^1\) Working definitions of peatland habitats are outlined below
Throughout the review and in each of these four topic areas the underlying aim is to investigate the question of “what do we know/not know?”. By better understanding knowledge gaps we can start to address what actions need to be taken now in order to prepare for future changes.

1.2 Working Definitions
In addition to some definitions already detailed above, the following assumptions and definitions of prescribed burning and of peatlands, are made:

a) Peats are defined as deep peats with an organic layer deeper than 40 cm depth which coincides with the definition used within the Soil Survey of England and Wales, or 50 cm deep in Scotland.

b) The review includes peat soils in raised bog as well as blanket bog and mires in both upland and lowland settings. The review does not consider wetlands with large expanses of standing water nor peat soils converted for arable agriculture.

c) In geographical terms the review considers data from the UK as a priority but also considered data from Europe and North America, but data from the Arctic or which could be considered as tundra were excluded.

d) The context in which peat soils are considered is not stationary especially in the light of climate change, but given the scarcity of studies it was decided not to discriminate on the grounds of age of the study.

e) Managed burning is considered as any deliberate and prescribed burning of vegetation on peat soils. It does not include the burning of peat soil as fuel and deliberate acts of arson. Although this definition does not include accidental fire we will consider the impact of prescribed fires that become runaway burns. We consider burning across a range of vegetation and for a range of reasons including: increasing grouse and sheep production; and for wildfire risk reduction.

f) Terms such as fire intensity and fire severity are often used interchangeably. The definitions of Keeley (2009) are useful when considering impacts of fire: fire intensity is a measure of the radiant energy released from the fire; fire, or burn, severity is the organic matter loss during combustion and the ecosystem response is a measure of the resilience of the ecosystem to recover to the pre-burn conditions. Further information on these important definitions are given in section 2.1

g) The exact definitions of prescribed burning and of peat soils may vary between studies and the review has had to accept the author’s individual statements.

h) We have to be generous with the authors’ definitions regarding peatland type, classification or habitat. We recognise that many useful peatland classification exist, however, given the nature of our data and the size of our dataset, imposing any particular set of subdivisions may prove fruitless as they are not represented in the data.

i) The review has to rely on the individual authors and a critical assessment of data quality of any individual study is not possible within this review, however, studies will be classified depending upon their status, e.g. studies in peer-reviewed journals will be considered of superior quality to project reports.

j) The review attempts to consider both magnitude and direction of any effect.

2. Aims of Burning and Current Practice, Drivers of Change

Fire has been a common part of the uplands of the UK for many hundreds, even thousands, of years. Whilst there is evidence that fire may have been used to clear land since Neolithic times (Fyfe et al., 2003), it was not until the late medieval period when burning started to become a
common management practice. Records show that burning, or ‘swaling’ was a common practice on Exmoor in the 1300s to improve pasture (Rackham, 1986) and records in Scotland show the term ‘muirburn’ occurs in an Act of Scottish Parliament of 1400 (Dodgshon and Olsson, 2006).

The use of managed burning for habitat maintenance for red grouse (*Lagopus lagopus scoticus*) spread rapidly during the middle of the 19th century. Prior to this, burning was carried out to improve grazing for sheep (*Ovis aries*) and red deer (*Cervus elaphus*) and this practice also continues today. Burns for sheep and deer management are often larger than those for grouse and have the aim of creating large areas of regenerated vegetation. The current method of strip burning was known to occur in the 19th century, however, it was not until an inquiry into grouse disease in 1911 (Lovat, 1911) that the practice started to become codified.

Management for red grouse aims to create a mosaic of new growth for forage whilst maintaining older stands of heather for cover. Through repeated cycles of burning *Calluna* is prevented from reaching a degenerate phase (Hobbs and Gimingham, 1987). In the 1970s and 1980s a series of works investigated the effects of burning on heathland vegetation (e.g. Hobbs, 1984; Hobbs and Gimingham, 1984a; Hobbs and Gimingham, 1984b)

Studies have also investigated the impact of burning on other biophysical processes, but in recent years, concern over the nature of peatland carbon stores have prompted a series of works looking at the impact of burning on carbon stores and fluxes (e.g. Garnett et al., 2000; Ward et al., 2007)

Grouse shooting, and therefore, by association, moorland management and managed burning, is an important economic activity. Grouse moors support many jobs directly, i.e. gamekeepers, but also many secondary jobs e.g. local bed and breakfasts. McGilvray (1995) calculated grouse shooting provided £14.7 million in wages in Scotland in the early 1990s and it supported 904 full-time jobs in the hotel industry. The larger sporting shooting industry has been calculated to be worth £1.6 billion to the UK economy, with 12% or £120 million, spent on grouse-shooting in good grouse years (PACEC, 2006).

3. Status and Trends

3.1 Types of Burning

There are at least four different types of fire (Glaves and Haycock, 2005) although definitions vary across the world, these are:

(a) Prescribed burning, sometimes called managed or controlled burns, where the fire has been deliberately lit for management purposes. In the UK prescribed burning is controlled by legislation.

(b) Wildfire – according to the definitions of (CIFFC, 2002; NWCG, 2008) are any unwanted or unplanned fires; this can be sub-divided into at least three types:
   a. Escaped prescribed fire, where the fire has moved beyond the planned fire boundary and is out of control.
   b. Human-induced fires started accidentally or negligence (barbecues, smoking, discarded glass) or started deliberately (arson)
   c. Natural-fires started by lightning.
The review of terminology by Keeley (2009) provides a good systematic framework to consider the impacts of these different types of fires and argues that there should be a separation in thinking over these different terms and specifically for fire intensity, fire/burn severity and ecosystem response, for example:

(a) Fire intensity should be confined to a measurement of the energy output from the fire.
(b) Fire/burn severity is the organic matter lost during combustion
(c) Ecosystem response is essentially a measure of the resilience of the ecosystem to recover to the pre-burn conditions.

3.2 Geographical Extent
Managed burning is spatially extensive and recent surveys, using aerial imaging, have estimated that up to 114 km$^2$ of the UK uplands are burnt annually (Yallop et al., 2006b). Natural England (2010a) report that 15% of English peatlands have been subjected to managed burning which equates to 1000 km$^2$ out of 6780 km$^2$ of deep peat. Defra (2010) estimate that 18% of UK peats have been subject to managed burning which is approximately 3150 km$^2$. However, the proportion of burning varies significantly across the UK – 1-2% in Borders and Grampian (Hester and Sydes, 1992) to 20% in the North Pennines AONB (Yallop et al., 2006a). Yallop et al. (2005), using historical and current aerial photography, show that in Calluna-dominated communities 38% of the area was managed by burning. In areas not normally managed for grouse, these proportions range from 1-16% (Glaves and Haycock, 2005).

The typical length of rotations is an alternative way to estimate the area under burning management as it is the reciprocal of the area burnt i.e. 1/20$^{th}$ of the land burnt = 20-year rotation. Recommended rotations length is between 15-20 years (Defra, 2007a), however, again regional differences lead to a variety of common rotation lengths (Shaw et al., 1996). Much of this variation is dependent on the local growth rate of the vegetation and both the Muirburn Code and Burning Code highlight the need for burning rotations appropriate to the local conditions (Defra, 2007a; SEERAD, 2001a) with shorter rotations required in the warmer southern parts of the UK, and perhaps longer rotations further north. However, both Codes state that there should be a presumption against burning on blanket bog unless agreed to by the appropriate statutory authority e.g. Natural England, Scottish Natural Heritage (Defra, 2007a; SEERAD, 2001a).

From a national survey of aerial photography, Yallop et al., (2005) show that burning appears to have increased between the 1940s and 1970s but there is little change from the 1970s to 2000, though when photography from the National Parks is included a significant increase in burning is recorded from 1970s to 2000. This demonstrates the localised regional variations in burning (Yallop et al., 2006b). Indeed in a study of burning on the High Peak estate, Derbyshire, increases in burning, both the number of burns and total area burnt, during the 1990s were observed (Penny Anderson Associates, 2006). The authors suggest that these increases in the Derbyshire are due in part to the ESA agreements that grant aided an agreed burning programme. However, it should be noted that increases and decreases are also influenced by burning conditions and the authors note that decreases observed during 1999-2005 may be influenced by some particularly wet years leading to poor burning conditions. Davies (2008) points out that burning regimes should be viewed as part of a long-term series of changes over the last 150-200 years.

3.3 Timing of Burning
Managed burning is restricted to certain times of the year in order to protect ground nesting birds in the nesting season and to limit the chances of runaway wildfires in the hotter summer
conditions. Table 1 summarises the periods in which burning is allowed along with the principal legislation that covers each administration.

**Table 1. Legislation covering managed burning with legal burning season**

<table>
<thead>
<tr>
<th></th>
<th>Uplands</th>
<th>Lowlands</th>
<th>Principal legislation</th>
<th>Code</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Scotland</strong></td>
<td><strong>1st</strong> October – 30th April (above 450m)</td>
<td><strong>1st</strong> October – 15th April (below 450m)</td>
<td>Hill Farming Act 1946</td>
<td>Muirburn Code (SEERAD, 2001a) Muirburn code supplement (SEERAD, 2001b)</td>
</tr>
<tr>
<td><strong>Northern Ireland</strong></td>
<td><strong>1st</strong> September – 14th April</td>
<td>Game Preservation Act (N.I.) 1928, Chapter 25 as amended by the Game Law Amendment Act 1951, Chapter 4</td>
<td>Game Preservation Act (N.I.) 1928, Chapter 25 as amended by the Game Law Amendment Act 1951, Chapter 4</td>
<td></td>
</tr>
</tbody>
</table>

As Table 1 shows, the restriction period for burning varies across the country and for uplands vs. lowlands. One of the outcomes of the Glaves and Haycock review (2005) was to say that “the Panel do not recommend any changes to the existing burning dates at present” [emphasis from Glaves and Haycock (2005)]. However, it goes onto say “though, given that the impacts of controlled burning earlier in autumn are uncertain, the Panel supports the suggestion of further research on this”.

A recent review by the British Trust for Ornithology (BTO) that investigated the breeding periods of selected bird species in England, showed that some of the earliest egg laying attempts for species such as golden plover (*Pluvialis apricaria* (L.)) and lapwings (*Vanellus spp.*) may be made during the late part of March/early April i.e. within the current burning window in England (Joys and Crick, 2004). No data was available for grouse breeding dates. It should be noted that the fledgling dates for many of these species are after the current burning window (Joys and Crick, 2004). In light of these breeding dates and concern over early-emerging reptiles, some have suggested that to reduce the risk of damage to nests that the end of the burning season could be moved forward to the end of March.

### 3.4 Methods of Burning

The methods of preparing, igniting and controlling managed burns have been refined over many generations and today utilise the knowledge of the past with the technology of today. Traditionally burns would be started by paraffin kettles with a lit wick, a drip-torch (Davies et al.,
and, if no suitable natural fire break were available, an area would be burnt to create a fire break. Teams of keepers would use firebeaters to keep the fire in the designated area and to control its passing. Today many of these methods are still used but have been supplemented by pressurised flame-guns to start the fire coupled with various approaches to fire control including the use of fire fogging equipment, the creation of fire-breaks using mowers on quad bikes with low impact tyres and the spreading of fire-retardant foam. These innovations can allow burning to take place in conditions that otherwise would not be ideal for traditional burning and allow much better fire control management.

Burning techniques may also have an influence on fire severity. Traditional techniques, such as the use of ‘fire kettles’ (paraffin containers with a wick) to light vegetation only work well with relatively dry vegetation (and hence often can only be started late in the day). By contrast, the more recent use of gas or diesel pressurised burners allows burning of damper vegetation and burning to be carried out in a longer weather window and provide the burning of vegetation with a higher moisture content (G. Eyre, pers. comm.). The latter technique has been described colloquially as “cool burning”, but it would be better described as “fuel-assisted burning”.

However, it must be noted that all prescribed management fires require a detailed local knowledge of the area and understanding of fire. By passing on the inherited knowledge of managed burning from head keeper to under keeper, these vital skills can be preserved. Additionally, courses on moorland burning held by organisations such as the Heather Trust, and links with the Fire and Rescue Service through regional fire groups all allow good practice to be shared.

Meteorological conditions can affect the fire conditions significantly and the Muirburn code (SEERAD, 2001a) and the Heather and Grass Burning Code (Defra, 2007a) both specify wind speeds above which burning can and cannot occur. As fire movement through the vegetation will be restricted at very low wind speeds, a low wind speed will self-regulate burning. Other conditions related to the weather on the day of burning such as air temperature and moisture have been shown to affect the amount of biomass consumed during burning (Clay and Worrall, in preparation).

4. Effects on Ecosystem Services and Biodiversity – Rationale and Methodology

UK peatlands have multiple land uses and provide many outputs enjoyed by multiple stakeholders (Holden et al., 2007). These outputs often referred to as ‘ecosystem services’ are services that the environment provides for the well-being of humans such as clean air, water and food. Ecosystem services can be grouped into four categories following to the Millennium Ecosystem Assessment definitions (Millennium Ecosystem Assessment, 2005): provisioning services (ecosystem products e.g. food and fibre); regulating services (including process such as climate regulation, flood regulation); cultural services (non-material benefits from ecosystems e.g. spiritual fulfillment, recreation) and supporting services (necessary for the production of other ecosystem services, e.g., soil formation, photosynthesis and nutrient cycling).

The impact of burning on the following ecosystem services are considered in this report:

- Regulating services:

2 http://www.moorsthroughfuture.org.uk/mftf/information/FOG.htm
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- Carbon storage and sequestration for climate change
- Wildfire regulation
- Water quality
- Erosion control

- Provisioning services:
  - Food and wool from game and sheep

- Cultural services:
  - Landscape value
  - Cultural heritage
  - Field sports
  - Biodiversity

In order to calculate the importance of burning on each ecosystem service, a formalised review was adopted in a similar fashion to the approach detailed in Worrall et al. (2010). Systematic review with or without statistical meta-analysis is now standard practice in medical research as initiated by the Cochrane Collaboration (http://www.cochrane.org), and it has been used in conservation, e.g. Collaboration for Environmental Evidence (Pullin and Knight, 2001; Pullin and Knight, 2003) but has been applied sparingly elsewhere in the environmental sciences.

Current literature both published peer-reviewed articles and the ‘grey’ literature e.g. reports, was reviewed and results are drawn up in Tables 4-8 throughout this report. Table 2 details the key for the tables.

Table 2a. Key for symbols used in Tables 4-8

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>↑</td>
<td>Increase in the magnitude of the component</td>
</tr>
<tr>
<td>↓</td>
<td>Decrease in the magnitude of the component</td>
</tr>
<tr>
<td>↔</td>
<td>Increases and decreases found</td>
</tr>
<tr>
<td>×</td>
<td>No significant effect for that component</td>
</tr>
</tbody>
</table>

Table 2b. Key for cell shading used in Tables 4-8

<table>
<thead>
<tr>
<th>Cell shading</th>
<th>Classification</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Original study from within UK</td>
</tr>
<tr>
<td></td>
<td>Original study from outside the UK</td>
</tr>
<tr>
<td></td>
<td>Review article</td>
</tr>
</tbody>
</table>

To allow for comparison between studies, in each table a column indicates the habitat in which the study was conducted was included, however, it has not always been possible to make these consistent between studies.
5. Effects on Ecosystem Services and Biodiversity – Review Results

5.1 Biodiversity

Biodiversity in its simplest definition is the variety of life in a given ecosystem and is often used as a measure of health of a system. UK peatlands support many BAP (Biodiversity Action Plan) habitats such as upland heathland and blanket bog and are the habitat for some BAP species such as grey mountain carpet moth *Entephria Caesiata* and *Sphagnum balticum* (Natural England, 2010b), though many of these species are also associated with a range of priority and non-priority habitats. For example, blanket bog, although does not support a large diversity of species they are important for a number of specialist species (Natural England, 2010b).

Peatland habitats are complex mosaics of inter-linked vegetation supporting a variety of flora and fauna. Managed burning alters the natural state of the uplands by creating this mosaic and by preventing scrub invasion, though it has been shown to reduce biodiversity and alter more ‘natural’ peatland communities.

They also provide a habitat for bird species such as curlew *Numenius arquata* (L.), golden plover *Pluvialis apricaria* (L.), black grouse *Tetrao tetrix* (L.), merlin (*Falco columbarius* Linnaeus), hen harrier (*Circus cyaneus* L.), short-eared owl *Asio flammeus* (Pontoppidan) and ring ouzel *Turdus torquatus* (L.) (Robson, 1998; Thompson et al., 1997; Whittingham et al., 2000; Whittingham et al., 2001).

Much of the research detailing the impacts on flora and fauna was comprehensively reviewed by Tucker (2003). A comment from this review was that much of the regeneration observed following fires depends on the pre-fire vegetation condition (e.g. initial floristic composition), the rotation length of burning and the fire conditions on the day of burning. Other factors such as pollution and grazing pressure will almost certainly interact with the post-fire succession. Therefore any general conclusions on the impact of burning on biodiversity have to be treated with caution.

The impact of burning on biodiversity can be split into the effect on the flora of peatlands (Table 4) and the impact on the fauna (Table 5).

5.1.1 Flora

There are two contrasting points of view with respect to the impact of fire on plant biodiversity and this to some extent depends on: (a) what is considered to be the historic vegetation; (b) the current vegetation, and indeed the vegetation that is to be conserved under existing conservation legislation; and (c) the potential target for the future.

**The historic vegetation:** There are published works, based on observational accounts that some species are intolerant of fire and are damaged or even extirpated from a site after burning. Some of these are noted in Table 3 and 4. Many of these references also acknowledge that other factors such as overgrazing, pollution and particularly drainage may be involved. In addition, many do not differentiate between prescribed burning and wildfire.

It can be argued that the totality of management on sites where these species were present has led to their decline. However, many of these species are relatively rare and no not occur on many current peatlands where prescribed burning is implemented. There are also accounts that
short-rotation burning favours other species, for example *Rubus chamaemorus* (Rawes & Hobbs, 1979).

**The current vegetation:** It has been argued that the current burning regime reinforces a *Calluna*-dominated vegetation that is relatively low in species (McVean and Ratcliffe, 1962; Rodwell, 1991). On this sort of vegetation, the current burning management is applied mainly for grouse and sheep, but at the same time it maintains a vegetation of relatively low biomass, and hence fire hazard. Where burning is not implemented the biomass increases greatly and will have a very high burn severity when wildfire strikes. Where this occurs the ecosystem response will also be severe as has been shown in the North York Moors after the 1976 fires (Maltby et al., 1990).

**The potential for the future:** Studies in the Peak District (Harris & Marrs, unpublished data) have shown that on moorland managed by prescribed burning there is a long-term reduction in species diversity after burning, and that if left unburned for 50 years there is no increase in species. Moreover, there are very few propagules of plants or bryophytes in the surface soil and litter. Thus, on these admittedly degraded peatlands there is very little hope of restoring more diverse communities without substantive intervention. Such interventions might include wetting the peat by gulley blocking and the addition of new species. However, all of this would have to be carried out against a constant threat of summer wildfire.

Other areas many not be as degraded as these Peak District moorlands, and clearly where there is a more diverse flora of peat-forming species then maintenance of these mire communities or their restoration may be easier.

*Sphagnum* species are key peat-forming species; however, there is little research into the effects of fire on their survival and recovery. *Sphagnum* may survive low intensity burns (Hamilton, 2000) though in extreme severe wildfires such as those on the North York Moors in 1976, *Sphagnum* species may be removed entirely (Maltby et al., 1990). In their study of burning and grazing at Moor House, Rawes and Hobbs (1979) showed that *Sphagnum* did recover following burning following a period of *Eriophorum vaginatum* dominance.

It is currently untested whether repeated cycles of burning leads to replacement of *Sphagnum* species, though hummock formers may survive fire better due to their higher moisture retention (Peatscapes Project, 2008). *S. tenellum* (Lindsay and Ross, 1994) and *S. compactum* (Okland, 1990; Slack, 1990) have been shown to be colonisers of burnt areas.

Burning has been shown to lead to a decrease in many vascular plants, mosses and lichens. Table 3 details some reports that detail species that have declined where burning has been implicated in the decline.
Table 3. Species that have been reported to have declined in upland habitats of the UK, and where burning has been implicated in the decline, often in conjunction with other environmental factors such as over grazing and drainage.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Shrub/forb</th>
<th>Graminoid</th>
<th>Fern &amp; allies</th>
<th>Bryophytes</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wigginton (1999)</td>
<td>Genista pilosa, Scheuchzeria palustris, Tuberaria guttata</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Stewart et al. (1994)</td>
<td>Andromeda polifolia, Betula nana, Arctostaphylos alpinus, Orthilia secunda</td>
<td></td>
<td>Lycopodium annotinum</td>
<td></td>
</tr>
<tr>
<td>Preston et al. (2002)</td>
<td>Arctostaphylos uva-ursi, Juniperus communis, Trientalis europaea</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Page (1997)</td>
<td></td>
<td></td>
<td>Blechnum spicant, Lycopodium clavatum</td>
<td></td>
</tr>
</tbody>
</table>
For the most part the response of the vascular plants to burning on modified bog is a disturbance–induced response centred on the regeneration cycle of the most common dominant species, *Calluna*. Thus, at Dinnet Moor on Deeside a reduction in species richness with time after burning was shown (Hobbs and Gimingham, 1984a). In what these authors term “species-rich” heathland (17-29 species in the 0-25 year period), they reported a reduction in grass, forb and lichen growth. Indeed they reported little grass and forb regrowth in the older stands. In a similar single-site study of burning on lichen diversity, the immediate effect of fire was to reduce lichen diversity, however it recovered within 20 years, and thereafter declined (Davies and Legg, 2008). Stands more than 25 years old generally had a lower diversity than stands 10-15 years old. Taken together the literature suggests that there is a flush of species in the immediate post-burn phase followed by a decline. These general conclusions have been corroborated by a recent multi-site study in Derbyshire (Harris & Marrs, unpublished). JNCC notes that fire as a disturbance regime may be important but little research has been done other than for dry dwarf-shrub heaths (JNCC, 2009).

Rotation lengths are extremely important as long vs. short rotation can have different effects on parameters (Hobbs and Gimingham, 1984a) and the pre-fire vegetation can affect the recovery of the vegetation and the community types following fire. Rawes and Hobbs (1979) investigated the effect of short and long term burning and found that *Calluna* regeneration from seed and by vegetative regrowth was greater in the short rotation plots. When combined with light grazing, *Rubus chamaemorus* was considerably more abundant in the short 10-year rotation burn compared either to the 20-year rotation or a vegetation allowed to recover for 50-years. This study was carried out from a heather management perspective. Nevertheless, this result is consistent with those of Hobbs & Gimingham (1984a) and Davies & Legg (2008).

It is also worth considering the impact of prescribed burning on *Calluna* recovery. This is entirely dependent on the mode of recovery of the *Calluna*, whether from seed or from vegetative means, or a combination of the two (Marrs, 1988). On deep peats or vegetation in the more oceanic parts of the UK there is likely to be regeneration from both resprouting and seed. Additionally, layering (Scandrett and Gimingham, 1989) is an another important regeneration method for peatlands. However, the ability of the Calluna to regenerate via resprouting reduces with age (Marrs, 1986; Marrs, 1988; Miller and Miles, 1970). Therefore, we would expect old Calluna stands and stands that are subject to severe wildfires, to rely almost entirely on the seed pathway after burning. To obtain rapid regeneration burning must be applied at the most appropriate rotation.

In lowland heaths in more continental climates, admittedly these will almost certainly be on podzols rather than peat, regeneration is mostly from seed (Marrs, 1986; Marrs, 1987; Marrs, 1988).

### 5.1.2 Fauna

Of the studies that investigate burning effects on peatland fauna, most have studied the impact on bird species. Table 5 shows some of the observed changes to bird populations with burning. For a comprehensive review see Pearce-Higgins et al. (2009) where much more detail can be found on bird numbers, density, breeding success and grouse moor management and vegetation cover. Burning appears to benefit some species e.g. Golden plover but at the detriment of others e.g. Meadow pipit. Grouse numbers have been correlated to managed burning (Section 4.4, Table 8). Studies that investigate the link between vegetation and birds find that most birds show an association for short open vegetation that would be produced through burning. However, it must be noted that it can be hard disentangling the effects of
managed burning from that of estate management such as predator control and also the
general effects of changes in vegetation architecture.

Soil fauna such as Enchytraeid worms has been shown to play an important role in carbon
cycling (Cole et al., 2002). However, increases (Mallik and FitzPatrick, 1996; Maltby and
Edwards, 1984) and decreases (Brown, 1986) in soil fauna have been observed with burning.

Data on the effect of burning on invertebrates is equivocal; increases in spiders and beetles
have been observed (Usher, 1992), but impacts on species such as Lepidoptera (MacDonald
and Haysom, 1997) and butterflies such as the Large Heath butterfly (Dennis and Eales, 1997;
Dennis and Eales, 1999) show increase and decreases.

There is little data for mammals – only those grouse moor studies that also include species such
as hares and rabbits (Hudson, 1992). Tucker (2003) suggests that burning practices that favour
grasses at the expense of heather would lead to greater rabbit and vole populations. This is
derived from their known habitat requirements. Mallon et al. (2003) concurs with Tucker’s view
of predicted hare numbers.

Research into the effect of burning on stream biota has been noted to be lacking, however,
Ramchunder et al. (2009) propose a conceptual model that hypothesises likely effects of
managed burning on stream ecosystems and biota. They suggest that if managed burning is
expected to increase suspended sediment, primary producers will be smothered, altering the
balance between grazers e.g. mayflies (Heptageniidae), but increase in abundance of collector-
filterers such as black fly larvae (Silmuliidae).

Table 4. Effects of managed burning on the flora of peatlands

<table>
<thead>
<tr>
<th>Author</th>
<th>Bryophytes</th>
<th>Calluna vulgaris</th>
<th>Graminoids</th>
<th>Molinia caerulea</th>
<th>Vaccinium myrtillus</th>
<th>Floristic Diversity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward et al. (2007)</td>
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<td>McVean and Ratcliffe (1962)</td>
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<td>Marrs et al. (2004)</td>
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<td>Rodwell (1991)</td>
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<td>Stewart et al. (2005)</td>
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<tr>
<td>Stewart et al. (2004a; 2004b)</td>
<td>↑ long rotations</td>
<td>↑ Eriophorum short rotations</td>
<td>↑ short rotations</td>
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<tr>
<td>Hobbs and Gimingham (1984a)</td>
<td>↑ long rotations</td>
<td>↑ E. vaginatum short rotations</td>
<td>↑ short rotations</td>
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</tr>
<tr>
<td>Tucker (2003)</td>
<td>↑ long rotations</td>
<td>↑ E. vaginatum short rotations</td>
<td>↑ short rotations</td>
<td>®</td>
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</table>

® = rapid regeneration

3 Attempts to impose a universal classification on these disparate studies has proved impossible
Table 5. Effects of managed burning on the fauna of peatlands.

<table>
<thead>
<tr>
<th>Author</th>
<th>Upland bird species*</th>
<th>Soil fauna</th>
<th>Invertebrates</th>
<th>Mammals</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Golden Plover</td>
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<td>Maltby and Edwards (1984)</td>
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<td>Brown (1986)</td>
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<td>Mallik and Fitzpatrick (1996)</td>
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<td>Tharme et al. (2001)*†</td>
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<td>Whittingham et al. (2001)</td>
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<td>Smith et al. (2001)</td>
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<td>Thompson et al. (1997)</td>
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<td>Usher (1992)</td>
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<td>MacDonald and Haysom (1997)</td>
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<tr>
<td>Dennis and Eales (1997; 1999)</td>
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<tr>
<td>Hudson* (1992)</td>
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</table>

* dealt with grouse moor management rather than burning per se
† arrows are for bird density see Pearce-Higgins et al (2009) for breeding success or population change

5.2 Hydrology
Burning can alter the hydrological status of a peatland through changes to the amount and nature of water flow and through changes to the water quality such as changes in pH.

5.2.1 Flow of water
Although there are several studies that detail the runoff responses following wildfires (e.g. DeBano, 2000; Doerr et al., 2006; Johansen et al., 2001) there are few studies that deal with Grouse are dealt with separately in Table 7 as part of the economic drivers of managed burning.
runoff responses from managed burns. Greater amount of runoff and flashy hydrology have been associated with bare or eroded sites (Evans et al., 1999). These conditions may be present following burning which may lead to increases in runoff though Kinako and Gimingham (1980) have shown that erosion is limited to the first 2 year following burning through the re-establishment of vegetation. Of those that specifically look at managed burning and runoff occurrence, increases (Clay et al., 2009a) and no significant differences (Meyles, 2002) have been observed.

Rates of infiltration have been noted to change as a result of burning: Imeson (1971) suggested that rates increased (but did not actually measure them), whilst Mallik et al. (1984) found rates of infiltration decreased as soil pores became clogged with ash, resulting in increased rates of erosion. Burning in other settings has been associated with the development of water repellency that limits infiltration (DeBano, 2000). However, Mallik and Rahman (1985) demonstrated that water repellency in regularly burnt peat peaked within the first month after burning then declined to a minimum. Mallik and Fitzpatrick (1996) used thin section studies to show that porosity increased in recently, intentionally burnt soils but that any difference disappeared within 2-3 years of burning.

Through burning, vegetation composition can be altered (Section 4.1), leading to the dominance of particular species such as Molinia caerulea or Calluna vulgaris. By shifting vegetation to Calluna-dominated communities hydrological properties can be altered. Holden (2005) shows that Calluna vulgaris was associated with higher frequencies of soil piping. The rooting system of Calluna (and other woody plants) helps to preferentially channel flow in the upper layers of the peat.

By changing the dominant vegetation, rooting depths are altered and consequently the rate of evapotranspiration is affected. By altering the evapotranspiration rates water table depths may be altered. When discussing water table changes it is important to define the reference surface from which the measurement was taken. Many studies use the peat surface as this reference surface. Therefore, a shallow water table is closer to the peat surface than say a deep water table. Alternatively, depth to the water table (DWT) is another way of phrasing the previous statement. In this case an increase in DWT would equate to a deeper water table and a decrease in DWT would equate to a shallower water table.

Clay et al. (2009a) show that water tables were shallower i.e. closer to the surface on burnt plots, reflecting the dominance of grasses and forbs such as Eriophorum. The deepest water tables were found on the unburnt plots which were dominated by mature to degenerate heather. Here, the deeper more mature rooting systems drew the water table down. Similar results were found by Worrall et al. (2007a).

Clay et al., (2009a) ascribe their observations of water table to changes in the hydraulic conductivity of the peat under different management. In this instance, the hydraulic conductivity was the lowest on plots that had been burnt every 20 years. In contrast to this finding, Fisher (2006) found no significant difference in hydraulic conductivity with burning.

5.2.2 Water quality
For many, the issue of water quality is the most important question when investigating the impact of burning on ecosystem services. Some 70% of the UK’s fresh water is sourced from upland catchments (Bonn et al., 2009) and any management that negatively affects water quality and specifically colouration is likely to be in contravention of the Water Framework Directive (Anon, 2000; Bateman et al., 2006; Kallis and Butler, 2002)
There is a debate currently as to how burning affects the colour of water coming off peat covered catchments. Water colour is defined here as the amount of light absorbed at a particular wavelength for example at 400nm (Thurman, 1985). Section 4.3 details the impact of burning on DOC as part of carbon cycling process. Of those studies that investigate water colour, two show decreases, one shows increases and one shows no significant difference (Table 6). However, Clay et al. (2009b) whilst showing decreases in water colour found no significant difference between burning and DOC. This may suggest that the nature of the DOC has changed rather than its quantity.

Both increases (Allen, 1964) and decreases (Worrall et al., 2007b) in pH have been observed following burning. Changes to pH will have important impacts on post-fire vegetation succession.

The response of major metals and nutrients in soil water and runoff water varies depending on the species in question. Both Worrall and Adamson (2008) and Clay et al. (2010a) shows increases and decreases following burning. Worrall and Adamson (2008) observe lower Ca, Na, Mg and PO$_4^{3-}$ concentrations on burnt plots with only Al showing significantly higher concentrations on burnt plots. In the year following a managed burn Clay et al. (2010a) show significant increases in Fe, Na and K in soil water. Clay et al. (2010a) use these changes in water chemistry to investigate changes to source waters following burning. They found that following burning soil water becomes more soil water like and runoff water becomes more like rainwater. This partitioning of incoming rainwater may have important implications for runoff export from burnt catchments.

Table 6. Effects of managed burning on the hydrology of peatlands

<table>
<thead>
<tr>
<th>Author</th>
<th>Water Table</th>
<th>Runoff</th>
<th>Hydraulic conductivity</th>
<th>Water colour</th>
<th>pH</th>
<th>Metals</th>
<th>Nutrients</th>
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<tbody>
<tr>
<td>Clay et al. (2009a)</td>
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<td>Clay et al. (2009b)</td>
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<td>Clay et al. (2010a)</td>
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<td>Worrall and Adamson (2008)</td>
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<td>Worrall et al. (2007a)</td>
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<td>Meyles (2002)</td>
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<td>Fisher (2006)</td>
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<td>Allen (1964)</td>
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<td>Chapman et al. (in press)</td>
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<td>Yallop et al., (2008)</td>
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<td>Battle and Golladay (2003)</td>
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</table>

5.3 Carbon and greenhouse gas balance

Vegetation change (driven by management practice) may have a strong impact on DOC production. Evidence is building from a number of sources that vegetation cover is a key driver of DOC concentrations. Much of this evidence has been compiled into one document by

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5 Where increases are recorded on the water table column, this means that water table is closer to the surface.
Armstrong et al. (in review). *Sphagnum* and *Molinia* seem to be associated with low concentrations while *Calluna* is associated with higher concentrations of DOC. Thus if management alters the vegetation cover of sites then this might alter the C fluxes in the long term. However, field evidence is equivocal, Ward et al. (2007) and Clay et al. (2009b) and found no significant difference in DOC concentrations in soil and stream waters between burnt and unburnt sites. Yallop and Clutterbuck (2009) ascribed increasing DOC concentrations to increased use of burn management, while Worrall et al. (2007a) showed a significant decrease in DOC concentration. This range of observations is reflected in Table 7.

With regard to POC, no published study has direct information for POC fluxes from managed burnt areas; Clay et al. (in review) used relative numbers based upon suspended sediment concentrations at the Hard Hill plots, Moor House (Clement, 2005) and showed that POC ranges from 11-38 mg l$^{-1}$ on the experimental plots. In contrast, where wildfires occur then erosion losses have been shown to increase. Wildfires can burn deeper than well managed burns so that plant roots are killed leading to break up of the surface and physical erosion. They also tend to occur over much larger areas so erosion losses would be expected to be greater and to stand more risk of getting into water courses. There are many documented examples of extreme erosion associated with wildfire events (Maltby, 1980; Maltby et al., 1990; Tallis, 1997). Rapid erosion leads to very high POC export from the system.

There are fewer studies of gaseous exchange on sites under managed burning. Ward et al. (2007) found increases in gross ecosystem CO$_2$ fluxes of both respiration and photosynthesis in burned and grazed treatments plots relative to controls. Clay et al. (in review) found significantly higher primary productivity on recently burnt sites in comparison to unburnt control sites.

Garnett et al. (2000) examined long-term experimental plots at Moor House, North Pennines, and found that burning reduces peat accumulation in comparison to no burning. Recalculating the data of Garnett et al. (2000) based upon all of their data, shows that the mean difference between burnt and unburnt treatments was 2.3 kg m$^{-2}$ (not 2.48 as reported), this gives a mean effect of burning of 55 tonnes C km$^{-2}$ yr$^{-1}$ (not 73 tonnes C km$^{-2}$ yr$^{-1}$ as reported). Pietikäinen et al. (1999) working in Finnish mires determined that C sequestration at regularly burned sites was half that at unburned sites. The average C loss associated with a single fire was 2500 g C m$^{-2}$. Similarly, Kuhry (1994) used peat core data to demonstrate that rates of peat accumulation in Boreal Canada reduce with increased frequency of wildfires. However, these studies measure peat accumulation as a proxy for C accumulation. Clay et al. (in review) studied the Moor House plots further and showed that burnt sites were a mean source of approximately 117.8 g C m$^{-2}$ yr$^{-1}$ compared to unburnt sites with a mean source of 156.7 g C m$^{-2}$ yr$^{-1}$.

Many of the above studies only consider one component of the carbon budget and, as such, cannot comment on the complete carbon budget. Therefore, using a meta-analysis approach Worrall et al. (2010) combine results from existing studies and show that there are carbon benefits if managed burning ceased (Worrall and Bell, 2009; Worrall et al., 2010; Worrall et al., 2009). However, in the absence of any fuel management measures, there is a potential increase in fuel load and wildfire risk that could cancel out any carbon gains.

Many of these studies consider carbon fluxes or carbon stores in the peat soils and do not assess the carbon produced during fires in the form of char. The production of char, a refractory form of carbon (Preston and Schmidt, 2006), may have important implications for carbon cycling in peatlands due to the long mean residence time (Lehmann et al., 2008), and resistance to chemical agents (Bird and Gröcke, 1997). The amount of carbon produced during fires may be
of the same order of magnitude as some carbon flux components of the complete carbon budget even though they are temporally intermittent inputs of carbon (Clay and Worrall, in review).

Assessing the amount of fuel consumed and char produced during moorland fires has only recently been added to the complex debate about burning and carbon and consensus is still a long way off (Farage et al., 2010; Legg et al., 2010).

Fuel consumption during fires has been assessed though its implication in char formation has not been studied in much detail. No studies have been published that quantify the char production in managed burns but in Clay and Worrall (in review) the char production of a moorland wildfire is calculated and shows that approximately 14% of the above-ground biomass survived the fire and that of that biomass combusted in the fire 4% was converted to char. Although this shows a high consumption of fuel it is also within the range of fuel consumption for managed burning (Legg et al., 2010). The amount of char produced in this fire falls within the range of black carbon produced in fire in other settings (Forbes et al., 2006). However, char production may vary with fire behaviour and the completeness of combustion which may be related the temperature and duration of the fire. Further work is ongoing in the analysis of char production during a series of managed burns in the Peak district (Worrall and Clay, unpublished data).

**Table 7. Effects of managed burning on the carbon dynamics of peatlands**

<table>
<thead>
<tr>
<th>Author</th>
<th>Soil Respiration</th>
<th>Primary productivity</th>
<th>Methane</th>
<th>DOC</th>
<th>POC</th>
<th>CO₂</th>
<th>Dissolved</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ward et al. (2007)</td>
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<td>Worrall et al. (2007a)</td>
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<td>Ball (1974)</td>
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<td>Imeson (1971)</td>
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<td>Tallis (1987)</td>
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<td>Clement (2005)</td>
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<td>Yallop and Clutterbuck (2009)</td>
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</table>

The aim of managed burning is to create a quick moving fire that leaves behind a proportion of ‘stick’ (Defra, 2007a) without damaging the litter and underlying soil i.e. a ‘cool’ burn. Whilst there has been much discussion on what constitutes a ‘cool’ burn and the extent to which it is practised (Davies et al., 2010; Reed et al., 2009), a well managed burn would perhaps be expected to leave behind a greater proportion of biomass and leave critical layers such as peat forming Sphagnum mosses undamaged. Indeed a range of fuel consumptions from <30 to

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6 Water colour (absorbance at defined wavelengths) is often used as a proxy for DOC but the data on this has been summarised in the Table 5
7 Not directly measured, based on water table record
8 Based on Clement (2005)
100% for managed burning has been recorded (Farage et al., 2009; Kayll, 1966; Legg et al., 2010). In leaving unburnt and/or dead biomass following the fire, this is an additional carbon stock that needs to be accounted for when assessing the carbon impact of burning.

Finally, a note of caution is needed when reviewing the impacts of burning on carbon and greenhouse gases. The variety of locations and scales make overall generalisations difficult. Plot scale studies have shown different results to those at a catchment scale, particularly on the issue of DOC. These contrasting results may not be completely at odds with each other as processes between production site and catchment outlet may alter the quantity and quality of the DOC exported. Sources may be different as scale increases from plot to catchment; or sites may simply be distinct in the change that burning makes. For example, a site that has a high standing water table under burn management maybe be little affected by cessation of burning as the water table cannot increase much further.

5.4 Socio-economic impacts
Managed burning in the uplands of the UK has a clear economic impact e.g. grouse and sheep production, but also a wider social impact. This wider impact is often hard to quantify as it includes many intangible benefits such as landscape aesthetics.

5.4.1 Grouse production
Positive impacts have been observed in many studies of managed burning and grouse production (Table 8) and have been observed for many years (Picozzi, 1968). This may not be surprising as managed burning seeks to optimize habitats for grouse populations so increase in numbers or survival are likely to be observed. However, it must be noted that many of the studies that show positive outcomes (e.g. Tharme et al., 2001) investigate grouse moor management and do not study managed burning in isolation. Factors such as predator control are included in the management which makes it hard to separate out the effect of burning alone.

There is evidence that climate change is leading to changes in the timing of breeding and possibly diet in some peatland birds (National Ecosystem Assessment, in press). Climate change may interact with other drivers of change to affect grouse populations in unpredictable ways, for example a combination of sheep grazing and acid deposition provide the best explanation for the expansion of grasses into bog habitats (Van der Wal et al., 2003), which combined with climate change may influence the abundance of heather beetle (Rosenburgh and Marrs, 2010) leading to further habitat loss for grouse. Climate change may also increase the abundance of ticks at high altitudes (Gilbert, 2010), with effects on red grouse and hill sheep.

5.4.2 Livestock production
There has been limited published works that investigate the impact of burning on sheep production (Table 8). In one of the few works Lance (1983) observed high sheep performance (15% greater lamb production and 32% greater liveweight production). The author points out that this is a single experiment and may not be representative of other soil or vegetation types. There are also anecdotal accounts that sheep distribution, and hence grazing utilisation of the moor, is enhanced in a moor that is actively burned. Where burning is not used the vegetation can become impenetrable to sheep. However, bog vegetation may not be very productive for livestock and conservation stocking rates for bog and bog restoration are very low. Sheep are not the only grazer in these settings, for example, cattle and deer production, but there are no available studies on managed burning and these grazers.
5.4.3 Landscape value and perceptions
Whilst surveys are commonly used in assessing perceptions of uplands areas such as National Parks (Peak District National Park Visitor Survey, 2005; Suckall et al., 2009), there are few studies from the UK that specifically look at the public’s perceptions of managed burning. These kind of studies are commonly conducted in USA and Australia especially in fire prone ecosystems (Bell and Oliveras, 2006; Vining and Merrick, 2008). Here the aim is to understand perceptions of prescribed burning as a method for reducing wildfire intensity/frequency.

5.4.4 Wildfire
Managed burns and wildfire are both part of the UK fire regime and interlinked processes (McMorrow et al., 2010). Managed burning consumes older heather and allows new growth and regeneration. Through this process fuel loads may be reduced so that wildfires are limited or even suppressed. This school of thought has long been thought as a beneficial by-product of managed burning for grouse or sheep. However, little empirical research (Table 8) has been conducted to show how managed burning interacts with wildfire – does managed burning reduce the likelihood of ignition, fire intensity or fire frequency? McMorrow et al. (2009) show a low empirical risk of wildfires on heather moor which they suggest may be due to managed fires reducing subsequent fuel load for later wildfires.

The risk of managed burns becoming wildfires has also received little attention. The Peak District National Park ranger reports between 1976 and 2004 record 341 wildfires. Of the 341 reported wildfires, 41 have an attributed cause and of those 41, ten have been attributed to managed burns, i.e. a little under 25% of wildfires with a cause are due to managed burning. However, when the area of the wildfires is considered of the 41 fires with an assigned cause, those due to managed burns represented 51% of the burnt area, i.e. fires from managed burns appear to have been bigger when they did occur.

There are data quality issues surrounding the recording of vegetation fires in the UK which makes any analysis difficult. Before the introduction of the Incident Recording System (IRS) in the UK, Fire and Rescue Services are unreliable on causes often having a “favourite” attributed cause which varied over time (Walker et al., 2009).

When considering the relative pros and cons surrounding managed burning and wildfire, there is an element of making a trade off over longer timescales: for example what is the cumulative impact of managed burning on a 10 year rotation over 50 years versus a wildfire on a no burn area with a return period of 50 years. To date this kind of assessment has not been done.

There is also a counter-balancing argument that managed burning encourages a fire-adapted ecosystem whereas the absence of burning would promote a more fire-resilient wet bog ecosystem.

Table 8. Effects of managed burning on some socio-economic activities of peatlands

<table>
<thead>
<tr>
<th>Author</th>
<th>Sheep production/numbers</th>
<th>Grouse numbers</th>
<th>Wildfire</th>
</tr>
</thead>
<tbody>
<tr>
<td>Picozzi (1968)</td>
<td></td>
<td>↑</td>
<td></td>
</tr>
<tr>
<td>Lance (1983)</td>
<td>↑</td>
<td></td>
<td></td>
</tr>
<tr>
<td>McMorrow et al. (2009)</td>
<td></td>
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<td>↓</td>
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<tr>
<td>Tharme et al. (2001)*</td>
<td></td>
<td>↑</td>
<td></td>
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<tr>
<td>Hudson (1992)</td>
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</tbody>
</table>
6. Practical Tools for Monitoring and Assessment of Managed Burning

Practical monitoring and assessment can operate at a range of scales and for a variety of endpoints. Remote sensing techniques including aerial photography (Yallop et al., 2006b) and hyper spectral imaging (McMorrow et al., 2004) have shown their potential for monitoring at the national or regional scale and allow for area of burning and age of burn to be assessed. This scale of monitoring can only be interpreted by the aid of well characterised individual burn sites of known history.

For assessing the impact of burn management at the individual burn scale a range of techniques have been employed including:

- Quadrat surveys (e.g. Price et al., 2003)
- Birds number counts
- Dipwells (e.g. Worrall et al., 2007a)
- Char analysis (Clay and Worrall, in review)
- Near-infrared spectroscopy (Clay et al., 2010b)

However, there is no one single measure or proxy by which the impacts of burn management on ecosystem services can be assessed.

7. Good Practice: Potential for Changing Peatland Management to Improve Delivery of Multiple Benefits

With reference to ecosystem services in this review, managed burning has been shown to bring benefits, neutral effects and harmful actions to UK peatlands. The literature on managed burning is primarily covers studies that focus on the presence or absence of a particular ecosystem service so that any changes to the style of burning e.g. rotation length or technique, is not covered. It follows, therefore that there is a large gap in the literature regarding best possible practice to optimise ecosystem services or particular ecosystem service.

However, this is not to say that optimal strategies could not exist in regions but that further research is required.

8. Potential for Policies to Encourage Good Management Practice

Managed burning on peatlands in the UK is regulated by a series of regulations (see Table 1) and supported by guidance issued in the Heather & Grass Burning Codes (Defra, 2007a; Welsh
Assembly Government, 2008) and in the Muirburn Code (SEERAD, 2001a) in Scotland. The regulations set out the season when burning may take place and guidance for carrying out burning safely and effectively. Separate groups consider burning in the different parts of the UK and there is little communication between the groups (see Technical Review no. 8).

Although its remit was relatively narrow, the Science Panel commissioned by Defra in 2005 to investigate evidence for the need to introduce changes to the Heather & Grass Burning Code concluded that there was no evidence to support any major changes to the code (Glaves and Haycock, 2005). However there now appears to be conflicting evidence about the current burning seasons. In Wales, the 2008 review of the Heather & Grass Burning Regulations shortened the burning season so that it ended on 31 March, rather than 15 April. This change is being considered in the other parts of the UK in order to protect breeding birds, although currently there is no conclusive evidence that this would be beneficial. Practitioners argue that a shortening of the season will reduce their opportunity to carry out the burning required to manage their moorland areas as often the only time that burning is possible is during April. In Scotland, the possibility of allowing burning under licence is being considered as a way to reduce the amount of burning needed in the spring, which has the potential to interact with breeding birds (Technical Review no. 8).

The predictions of warmer and wetter winters may bring into doubt the ability to complete the planned heather burning programmes and this could leave the areas with drier peat, which have a higher proportion of heather, at greater risk of damage from wildfires. Summer wildfires are likely to be hotter and have a greater risk of burning into the peat and destroying it. These fires are difficult and expensive to control and as a means of coordinating resources this risk has encouraged the formation of Fire Groups throughout the country, often led by the local Fire & Rescue Services (Technical Review no. 8).

Technical Review no. 8 considers a range of policy instruments that could facilitate sustainable peatland management, some of which could be used to alter the extent of managed burning in future. Options considered include creating markets to pay for peatland ecosystem services, information provision, capacity building, market incentives, classic regulation and state control. Capacity building in this context may include training in burning skills, as recommended in Defra’s (2007b) response to their consultation on the review of the Heather & Grass Burning Code. Although state control would not be appropriate in most British peatlands due to current patterns of land tenure, greater regulation of managed burning may be possible through rules and penalties. However, the use of incentives via existing agri-environmental schemes or the creation of new markets for ecosystem services (such as carbon) affected by managed burning may be the most economically efficient way of achieving widespread behavioural change.

9. Missing Data

Following each of the major reviews over the last 10 years into the impacts of managed burning (Glaves and Haycock, 2005; Gray and Levy, 2009; Tucker, 2003) many research priorities were identified and questions posed. Table 9 details the key themes from these reviews and asks whether the original question has been answered. In most instances the answer is no but recent and ongoing research in some areas has moved the understanding on to some degree in some areas. The table also details what research has been conducted since the major reviews and any ongoing projects that have yet to report their data.
As can be seen by addressing one area of research new questions arise out of this. For example, several studies into carbon and burning have been conducted since the major reviews adding information to the debates but have not yet given conclusive results. Many studies focus on single elements of the carbon balance and only one study examines a full carbon budget of a managed burn site (Clay et al., in review). However, even this study has its caveats. It was conducted on a small scale plot experiment in the North Pennines on a pristine site (Moor House) which is unlikely to compare with many sites around the UK e.g. the degraded peats of the Peak District. Indeed Gray and Levy (2009) question the transferability of Moor House results to other parts of the country. Many of the other works reviewed in this paper also come from the Hard Hill plots at Moor House.

Additional questions have also arisen out of this carbon work such as the intensity of the burns themselves - where they “hot” or “cool” burns? Some initial work from ongoing work in Northumberland and the Peak District suggests that the nature of the burn may dictate later carbon fluxes rather than the time since it was carried out (Worrall and Clay, pers. comm.) making the question of spatial heterogeneity and “hot” vs. “cool” a very important one.

Table 9. Key questions still to be answered at the end of the major reviews over the last decade with additional questions from an IUCN UK Peatland Programme Stakeholder workshop in July 2010. Questions are not necessarily direct quotes and may be paraphrased to combine several similar questions

<table>
<thead>
<tr>
<th>Question Posed/Further research required</th>
<th>Reference(s)</th>
<th>What data is available on this question?</th>
<th>Has the question been answered? If not has the understanding progressed</th>
<th>What further questions have emerged from the original question?</th>
<th>Are there any ongoing projects that are addressing this topic?</th>
</tr>
</thead>
<tbody>
<tr>
<td>General questions</td>
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<tr>
<td>What are the effects of repeated (serial) burning?</td>
<td>(Gray and Levy, 2009) (MacDonald, 2008)</td>
<td>Hard Hill plots only experiment with long term repeated burns</td>
<td>No</td>
<td></td>
<td>??</td>
</tr>
<tr>
<td>A specific review into burning in lowland habitats</td>
<td>(Glaves and Haycock, 2005)</td>
<td></td>
<td></td>
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<tr>
<td>What is the geographical extent of research into managed burning?</td>
<td></td>
<td></td>
<td>A mapping exercise would be required for this.</td>
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<tr>
<td>Ecological</td>
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<tr>
<td>How does burning affect peat forming species, in particular</td>
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<td></td>
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<tr>
<td>Question</td>
<td>Reference(s)</td>
<td>Field of study</td>
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<td>-------------------------------------------------------------------------</td>
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<tr>
<td>How does Sphagnum recover from burning?</td>
<td>MacDonald, 2008; Tucker, 2003</td>
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<tr>
<td>How does prescribed burning impact birds communities?</td>
<td>Glaves and Haycock, 2005; Tucker, 2003</td>
<td>Upland predation experiment, GWCT</td>
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<td>What is the optimal patchwork of burning within grouse territories?</td>
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<tr>
<td>How does burning affect invertebrate communities?</td>
<td>Hobbs and Gimingham, 1987; Tucker, 2003</td>
<td>EMBER?</td>
<td></td>
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<td></td>
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<tr>
<td>Fire behaviour</td>
<td></td>
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<tr>
<td>How does the interaction between grazing and prescribed fire impact peatlands?</td>
<td>Glaves and Haycock, 2005; Gray and Levy, 2009; Hobbs and Gimingham, 1987; Tucker, 2003</td>
<td>Hard Hill?</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What are the environmental conditions e.g. weather, topography, under which burning can be carried out safely?</td>
<td>MacDonald, 2008; Clay and Worrall, in preparation</td>
<td>Northumberland burns, EPSRC bid</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>What is the impact of variable fire behaviour on ecosystem services?</td>
<td>Glaves and Haycock, 2005</td>
<td>Northumberland burns??</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Impact of fire on major cycles in peatlands</td>
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</tbody>
</table>
## 10. Conclusions and Key Messages

- Managed burning has been shown to bring benefits for some ecosystem services.
- Equally, managed burning has been shown to bring dis-benefits or at best neutral.
- There is a gap in the literature surrounding burn management practice i.e. we cannot recommend changes in individual styles of burning or management.
- Knowledge gaps include:
  - The range of burn practice across the UK
  - Does managed burning prevent wildfire?
  - The direct link between an ecosystem service and the style of management e.g. grouse production, sheep production, and water quality.
- Particular concerns remain around the provision of certain ecosystem service from peatlands that this review could not resolve e.g. water quality (DOC).
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References


Davies, A., 2008. Review of the historical environmental changes in the UK uplands relevant to management and policy, Economic and Social Research Council (ESRC), Swindon.


MacDonald, A.J., 2008. Fire and compaction as management tools on raised bogs. ROAME No. R07AC207, Scottish Natural Heritage Commissioned Report No. XXX.


Rosenburgh, A. and Marrs, R., 2010. The Heather Beetle: a review. Report to the Heather Trust, available online at:


