Muirburning for grouse: *does it increase or decrease net carbon emissions?*

REVIVE

The coalition for grouse moor reform

An independent report by Dr Helen Armstrong

Commissioned by REVIVE

Contents

Foreword

Even if you think it is reasonable to rear grouse so they can be driven in front of the guns of rich people for the 'sport' of killing them, even if you are not bothered by the routine illegal killings of birds of prey and legal slaughter of incredible numbers of foxes, stoats, weasels, crows and other animals, the climate emergency means that the management of all the peat-rich grouse moorland in Scotland will have to change radically.

We are in a Climate Emergency. The recent reports from the United Nations' Intergovernmental Panel on Climate Change tell us that the impacts of climate change are already happening faster and to a stronger degree than predicted. They say there is a narrow window in time to do everything we can to reduce greenhouse gas emissions.

Scotland's peaty soils contain vast amounts of carbon. Around a fifth of Scotland's land area is covered in soils rich in peat and these contain nearly two billion tonnes of carbon; that's 25 times the amount in all the trees, shrubs and other vegetation in the whole of the UK. When peatland areas are in good condition they form new peat and lock in carbon from the atmosphere. But when they are degraded they release carbon back into the atmosphere. Around 80% of Scotland's peaty soils are degraded in some way, so how we manage them and particularly how we try to help them recover is vitally important at a local, national and global scale.

There has been much argument about the climate impact of the management of peaty areas of intensive grouse moors, particularly the issue of muirburn. This important report looks in detail at the evidence and finds that there is surprisingly little, partly because these activities on grouse moors are hardly regulated at all. We do not even know how much of our upland area is burnt each year. There is a voluntary code on muirburn but actual practice is often observed to be in breach of this code.

Contrary to surprising claims from the shooting industry that muirburn is good for reducing emissions, this report concludes, despite the paucity of evidence, that stopping even well-controlled muirburn would likely not increase overall carbon emissions and stopping badly done muirburn would be beneficial to the carbon balance.

With greater global scrutiny coming on the contribution of peat management to climate change, and the Scottish Government's commitment to license grouse moors, this report should be an urgent spur to make sure minimising climate emissions from muirburn and other activities is an essential part of the new licence proposals.

Dr Richard Dixon

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Summary

The evidence currently available does not support the claim that stopping muirburning for grouse would result in increased net carbon emissions caused by an increase in severe wildfires. Important information gaps would need to be filled to enable reliable predictions to be made, however it appears more likely that stopping muirburning for grouse would result in a reduction, rather than an increase, in net carbon emissions, even under climate change. This is more likely to be the case if increased resources are put into wildfire prediction, education, detection and mitigation. Continuing muirburning for grouse cannot therefore be justified on grounds of reducing net carbon emissions. Furthermore, reducing this practice would have many environmental, social and economic benefits that outweigh the small risk that carbon emissions would increase. A reduction in the area of land burned for grouse could be brought about through making adherence to muirburning best practice a condition of being granted a licence for muirburning and /or by allowing muirburn only where there is a clear biodiversity benefit.

Key points

- It has been claimed that muirburning for driven grouse shooting helps to reduce greenhouse gas emissions by preventing large wildfires that are likely to expose, or burn into, soil peat layers thereby releasing large amounts of carbon dioxide. It has further been claimed that this beneficial effect of muirburn will increase under climate change due to an increased risk of wildfires. To examine the validity of these claims, this briefing note uses available evidence to compare likely carbon emissions from regularly burned grouse moors with those likely from unburned heather moorland, both in the current climate and under climate change.

- Grouse moors that are regularly burned according to muirburning best practice are likely to be close to carbon neutral i.e. the amount of carbon emitted is similar to the amount sequestered. By contrast, where best practice is not adhered to, burned grouse moors are often likely to be net carbon emitters. No information is routinely collected on muirburning in Scotland but the evidence that exists indicates that muirburning over large areas of grouse moor may not be carried out in accordance with best practice guidance. Carbon emissions from these areas could be considerable but, without more information, they cannot be assessed.

- Unburned heather moorland, whether dry, wet or blanket bog, is a net carbon sink. If trees and shrubs start to colonise drier heaths, there may be a period when more carbon is released than is sequestered but this will reverse in time as the trees grow. Once established, woodlands store considerably more carbon than do heathlands.

- The limited information available on wildfire ignition sources indicates that, in the Scottish uplands, wildfires generally start either from 'escaped' management burns or are accidentally started from fires lit by recreational countryside users. There appear to have been only three large wildfires in the areas of Scotland managed for grouse in the last ten years. This indicates both that management burns for grouse rarely 'escape' control to the extent that large wildfires result and also that large wildfires are rarely started by other means in these areas. Some wildfires are, however, started accidentally by other means, especially by recreational countryside users and this source of ignition is likely to continue if burning for grouse stops. Currently it is not known how many wildfires are started in this way.

- Any wildfires that do occur in long-unburned drier heather moorland have the potential to spread rapidly and to cover large areas if not brought under control quickly or if there are no natural, or man-made, fire breaks. The chances of large accidental wildfires occurring could be reduced by increased public education of fire risk, especially in late winter /spring and summer, together with improved fire preparedness, forecasting of fire risk and moorland firefighting capability. A number of measures could be taken to further reduce the risk of damaging wildfires. These include: blocking of drains on peatlands; cutting or burning of firebreaks; targeted planting of broadleaved trees and shrubs around visitor hotspots; and grazing with cattle, or vegetation cutting, to reduce the amount of flammable vegetation and encourage the spread of less flammable plant species.

- Even if wildfires do occur on long-unburned heather moorland, if they do not expose, or burn into the soil then they will be carbon neutral in the long term. Wildfires on unburned, and undrained, blanket bogs are unlikely to burn into the wet peat or to cause much damage to bog mosses so are likely to be carbon neutral. Drier heather moorland that is not burned is likely to pass through a transitional phase during which there will be large areas with a high biomass of flammable heather. Over time, however, the flammability of unburned drier heather moorland will decrease as less flammable plant species colonise. Wildfires on drier heather moorland in the transitional phase, despite the flammability of the tall heather, may rarely burn the well-shaded moss and litter layers beneath the heather canopy. Very little is known about the conditions under which the moss and litter layers under a tall heather canopy dry out and it may be that this happens only after unusually long periods of warm, dry weather. More information is needed on the effect of different weather conditions on the moisture content of the moss and litter layers under long-unburned heather moorland so that improved predictions of the effects of wildfires can be made.

- In Scotland, climate change is likely to result in warmer temperatures at all times of year as well as wetter winters, drier summers and an increased frequency of extreme weather events. It is not possible to predict with certainty how these changes will affect the impact of stopping muirburning for grouse on carbon balance. It seems most likely, however, that they will result in a decreased chance of wildfires in late winter /early spring, when most wildfires currently occur in Scotland, and an increased chance of summer wildfires. The increased frequency of extreme events may result in extremely dry conditions occurring more frequently than currently. During such times, the likelihood of wildfire could be very high. Currently, however, we cannot predict the nature, or frequency, of such extreme events, nor their consequences for wildfire frequency or severity. It is not valid to make comparisons between Scotland and other parts of the World where wildfires are a major problem e.g. Australia, Greece or California. Many of these fire-prone areas are much hotter and drier than Scotland is currently or is likely to become in the next several decades. The vegetation in these fire-prone areas is also more flammable and /or is likely to burn more intensely, than is that in the grouse moor areas of Scotland, even where heather moorland has not been burned for several decades.

- To reliably predict the impact of the cessation of muirburning for grouse on carbon emissions, more information is needed in a number of key areas. These include: the extent of muirburn that does not currently adhere to each element of best practice; the importance of different wildfire ignition sources; the impact of different weather conditions on the moisture content of the moss and litter layers under a long-unburned heather canopy; the effect of improved wildfire risk prediction and communication, wildfire preparedness, and wildfire mitigation measures on reducing the risk of wildfires.

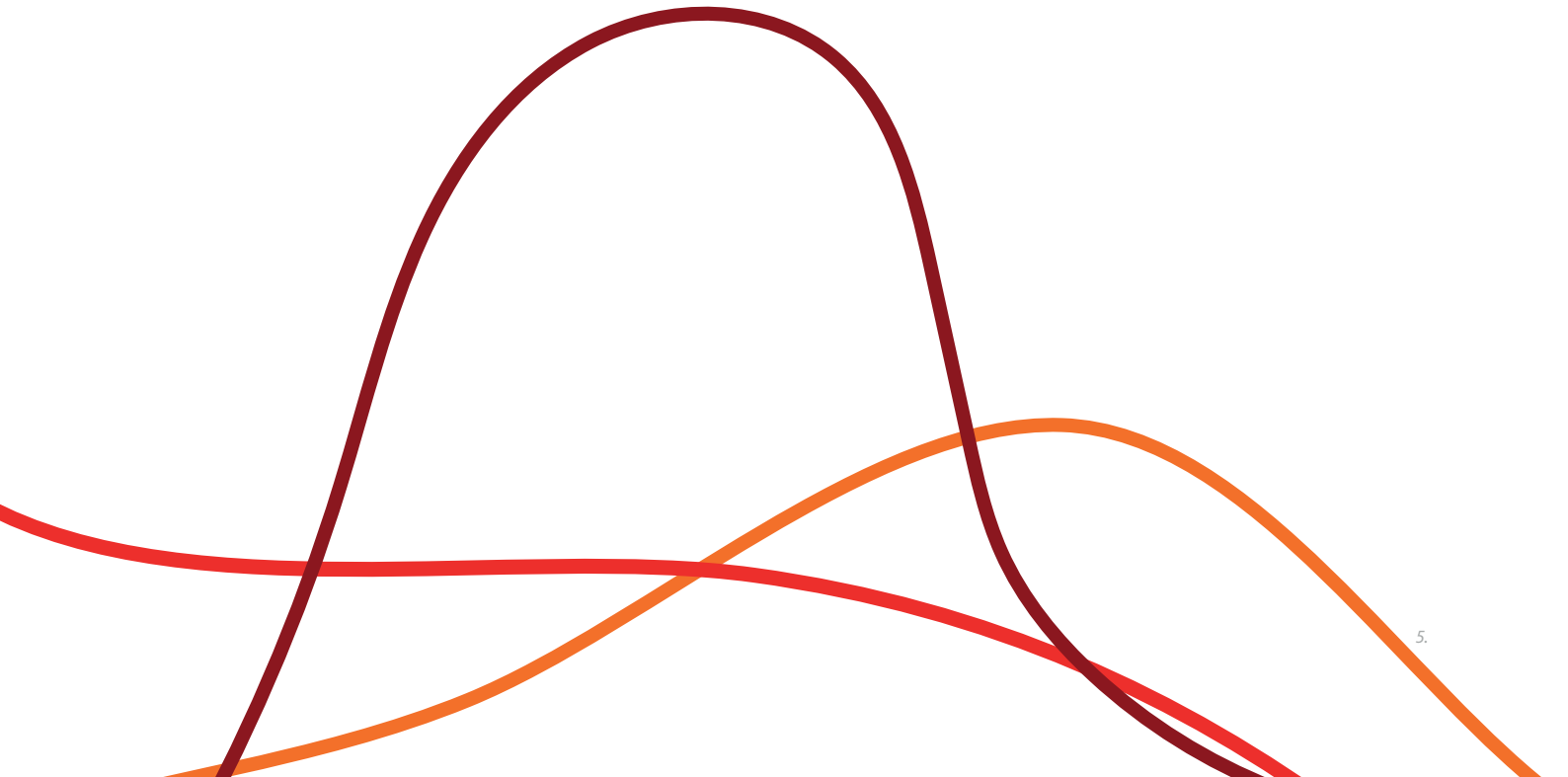
- The potential environmental, social and economic benefits of reducing muirburning for grouse and encouraging succession towards scrub and woodland on drier

heathlands outweigh what currently appears to be a small, and manageable, risk that there would be increased net carbon emissions from wildfires exposing soil or burning into peat.

- A first step towards reducing the carbon emissions from muirburning for grouse would be to make the granting of licences for muirburning conditional on adherence to best practice, and possibly also on the implementation of measures to reduce wildfire risk. Alternatively, or additionally, muirburn might be allowed to take place only on dry heather moorland where there is a clear biodiversity benefit. This would provide many of the benefits of reducing the area of Scotland subject to muirburn whilst also ensuring that areas of managed heather moorland are maintained for their biodiversity and cultural value.

Introduction

Regular patch burning of heather moorland takes place over a large area of Scotland as part of management to support driven grouse shooting. Claims have been made that cessation of this burning would result in a landscape more prone to large accidental fires that would be more likely to expose and /or burn into soil peat layers. As such, it is claimed that a landscape unmanaged by regular burning is likely to release more carbon into the atmosphere, through accidental burning of vegetation and peat, than one managed through regular patch burning (1). Furthermore, it is claimed that the risk of such wildfires will increase with climate change. These claims have been used to support the continuation of driven grouse shooting as a land use (1). This briefing note examines the evidence to support, or refute, these claims.



Background

History of muirburn, and its impacts, in the Scottish uplands

Although muirburning for grouse is often referred to as a traditional practice, it may not have become widespread as a management tool until as late as the 1890s (2). Prior to that, from around 1750 onwards, and earlier in the Southern Uplands, muirburn was carried out regularly and extensively to encourage the growth of new, green vegetation and young heather for year-round sheep grazing in the hills. This practice is still carried out today, especially in the west and north of Scotland. Muirburning for sheep tends to be in larger patches, and to be less controlled, than is muirburning for grouse. Before the change to year-round grazing with sheep, the hills were grazed only in summer and with a mix of cattle, sheep and goats. At this time, muirburning was likely to have been carried out much less frequently, and less extensively, than either muirburning for grouse today or than muirburning for year-round sheep grazing (2-6). In much of the Southern Uplands, muirburning from the medieval period onwards, together with grazing by domestic stock, is thought to have caused a transition from herb rich grassland to a mosaic of herb rich heathland and grassland. The intensification of both muirburning and grazing that came with the change to year-round sheep grazing is thought to have caused a further shift in the vegetation firstly to herb poor heathland and then, in many areas, to herb poor grassland dominated by unpalatable grasses (largely white bent, *Nardus stricta*, in the east of Scotland and purple moor grass, *Molinia caerulea,* in the west) (3, 4). The same transitions also happened in the Highlands on drier soils but with the transition stopping at herb poor heathland in many areas. From around 4,000 BP onwards, a gradual intensification of tree felling, stock grazing and burning caused the loss of most of the woodland and scrub that had previously covered much of the Scottish uplands (7).

Types of grouse shooting

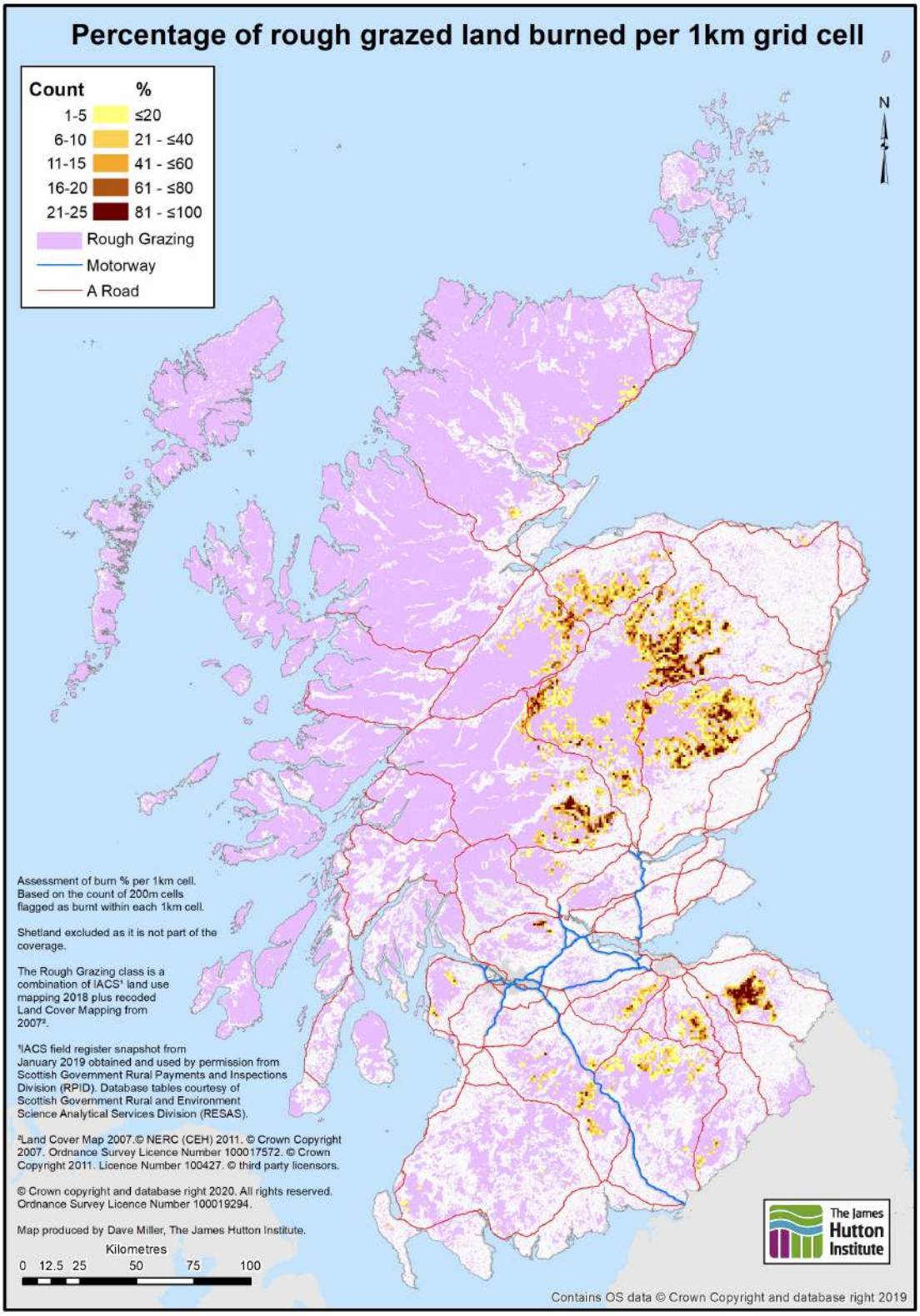
Driven grouse shooting is the practice of shooting grouse by driving them towards shooters who are hidden behind shooting stances, termed 'butts'. This practice became widespread on Scotland's heather moorlands around 170 years ago (8). Rotational patch muirburning, along with several other management activities, is needed to generate the high densities of grouse required for driven grouse shooting (9). Walked-up grouse shooting is the practice of walking through the landscape shooting red grouse that are flushed by the shooter and /or by their dogs. Walked up grouse shooting does not require the high densities of grouse, and so also the muirburning, that is needed for driven grouse shooting. Moors that are managed for driven grouse shooting are, nevertheless, also often used for walked up grouse shooting (10), particularly when grouse numbers are low. Although all moors used for driven grouse shooting will be managed using muirburn, there may also be a small number of estates where muirburning for grouse is practiced but where only walked up shooting takes place.

Location of areas of muirburning for grouse shooting in Scotland

Currently, most muirburing for grouse shooting takes place in the Cairngorms, Deeside, the Monadh Liath, the Angus Glens, Highland Perthshire, the Lammermuir Hills and other parts of the central and eastern Southern Uplands (Figure 1). In the past, muirburned grouse moors were also found in the west of Scotland but the wetter climate in the west is less favourable for heather and grouse and there are now very few managed grouse moors in this part of the country.

Figure 1. Location, and intensity, of muirburning for grouse in Scotland (15).

The figure shows the percentage of land subject to management burning for grouse in each 1 km square assessed. Assessments were made using satellite images. The figure is reproduced with the permission of the authors. Permission does not imply any endorsement by the authors, nor by the funders of their analysis, of any interpretations or conclusions drawn within this briefing note.



Area of land managed for grouse using muirburn

The area of Scotland that is subject to muirburn for grouse has most recently been estimated to be 163,000 ha (2% of Scotland's land area) (11).

Reason for muirburning for grouse

The shoots of heather plants form a large proportion of the diet of adult red grouse. The shoots on young heather plants are more nutritious than those on older plants. Older, longer heather is used by red grouse for shelter and nesting. Invertebrates, which make up a large proportion of the diet of chicks, are more abundant where there are patches of shorter vegetation. To create ideal conditions for red grouse and maximise their numbers, grouse moor managers burn moorland areas to create a mosaic of patches of older, taller heather and younger, shorter heather (9). Muirburning also prevents the encroachment of woodland and scrub onto heather moorlands.

Characteristics of muirburning for grouse

Best practice guidance for muirburning states that burned patches, or strips, should be no more than 50 m wide and may be several hundreds of metres long (12). This guidance applies to muirburning for sheep as well as for grouse. On driven grouse moors, burned patches rarely exceed around 2 ha in size and are normally much smaller. It is recommended that a patch of heather is burned again once it has reached 20-30 cm in height (12). This is likely to take between eight and 25 years depending on the growth rate of the heather (12, 13). No monitoring of burning frequency on grouse moors in Scotland takes place so there is no information available on how frequently patches of heather on Scottish grouse moors are, in practice, burned.

Legal restrictions on muirburning

Muirburning can only legally be undertaken between 1st October and 15th April although the season can be extended to 30th April on the authority of the land owner (14). The Scottish Government does not encourage this extension, however, as there are increased risks to ground-nesting birds in late April (14). A licence may be granted by NatureScot for burning out of season for the purposes of public safety, research or conserving, restoring or enhancing the natural environment (14). Only around twenty such licences were issued by NatureScot between 2015 and 2021, mostly for burning in summer (A. Coupar pers. com.). The purpose of the muirburning season is mainly to prevent burning during much of the breeding season of ground nesting birds and to avoid harm to reptiles coming out of hibernation (14). It also restricts burning to a time of year when the ground is more likely to be wet and so fires are less likely to burn into the moss, litter (dead vegetation lying on the soil) or peat layers. Aside from the legal requirement to burn during the muirburning season, there are a number of legal requirements that relate to burning safely, not causing damage to property, infrastructure, wildlife or areas designated for nature conservation and letting neighbours and land owners know when muirburning is planned to take place (12).

Muirburn. Copyright, Ruth Tingay

Muirburning best practice

Although not legally binding, best practice guidance published by the Scottish Government recommends not burning: in or near woodland (unless for nature conservation reasons); bracken areas; peatlands (defined as having a layer of surface peat of more than 50 cm in depth), bare peat or eroded areas; thin soils (less than 5 cm deep over underlying rock); summits, ridges or other wind exposed areas; steep hillsides and gullies; edges of waterbodies; areas subject to heavy grazing; areas previously identified by public bodies to be fire-free (14). It is further recommended that some patches of heather are left unburned (14). To reduce the chances of fires getting out of control it is recommended that burning is not carried out when it is too windy or when the vegetation is too dry (14).

Wildfires

Wildfires are fires, started deliberately or accidentally, that are out of control. In the UK, fires started by lightning are extremely rare since lightning is normally accompanied by rain (16). No systematic assessment of the ignition sources of upland wildfires is carried out in Scotland. The limited information that is available relates to the UK and suggests that, in the uplands of both England and Scotland, over 60% of wildfires may start as 'escaped' management fires that are used to manage vegetation for either sheep or grouse (16). Many of the remainder are ignited by sparks from campfires or stoves. Some fires are acts of deliberate arson but these are more frequent in the lowlands and in rural-urban fringe areas than in the uplands (16). Other accidental ignition sources include garden bonfires (17) and sparks from vehicles.

Heather moorland vegetation types

Burning for grouse takes place on vegetation types that are categorised as dry heath, wet heath and blanket bog. All these vegetation types have a heather (*Calluna vulgaris*) component, the amount of which can vary depending on ground conditions as well as past grazing and burning pressure. In general, drier heaths have a higher cover of heather than do wetter heaths and bogs. Draining of both wet heath and blanket bog can convert them into a vegetation type more like dry heath (18). This effect can be exacerbated by burning and /or heavy grazing (18, 19). When that happens, heather cover increases and the bog (*Sphagnum*) mosses, that are a major contributor to peat formation and carbon sequestration, are largely replaced with moss species that thrive on drier soils. It has been estimated that around 40% of the area burned for grouse in Scotland overlies deep peat that is currently, or has been in the past, functioning, carbon-capturing bog (13). If burning on dry heath is too frequent, or too infrequent (older heather does not always regenerate well after a burn), or if grazing pressure, especially in winter and /or after burning, is too high, the heather-dominated heath can turn into grassland (19).

Vegetation succession when muirburning stops

When burning on undrained blanket bog stops, it is likely that the effects of burning will reverse, with the cover of heather decreasing, that of bog mosses increasing and the surface becoming wetter (18). Undrained blanket bogs are too wet for trees to grow well but a few stunted trees or shrubs may appear, creating a habitat known as 'bog woodland' (20). On drier heaths, the heather will become taller and the stems more woody. Patches of taller heather will eventually collapse and die through ageing, heather beetle attack (21) or winter desiccation (22). Young heather, other dwarf shrub species, grass and herb species will grow in the gaps. In wetter areas, the heather that collapses may take root and start to grow again, perpetuating a high heather cover (23). If there is no source of tree or shrub seeds, or the grazing pressure is too high, both dry and wet heathland will remain in this 'transitional', treeless, state. Where there is a seed source, and the grazing pressure is not too high, shrubs and trees are likely to colonise and, after several decades, the heathland will begin to change into a shrubland or woodland.

Net Carbon emissions

Burning of living plants, dead plant material, peat or other soil organic matter results in carbon being emitted into the atmosphere, largely as carbon dioxide (CO_2). Growth of plants and deposition of litter and peat, or other organic matter, result in carbon sequestration. Under wet conditions, anaerobic (without oxygen) decomposition of organic matter can result in the production of methane (CH_4). Methane has a climate warming potential of around 28 times that of carbon dioxide but it has a half-life in the atmosphere of only around 12 years breaking down into carbon dioxide and water (24). The term 'net carbon emissions' is used to mean the balance between carbon emissions and carbon sequestration. If carbon emissions are greater than carbon sequestration then net emissions are positive. If sequestration is greater than emissions then net emissions are negative and there is net carbon sequestration.

Evidence

To test the claims that have been made about the effect of stopping muirburning for grouse on net carbon emissions we need to know:

1. Net carbon emissions from heather moorland managed for grouse by muirburn.
2. Net carbon emissions from long-un burned heather moorland.
3. Area of heather moorland likely to be burned by wildfires if management burning stops.
4. Net carbon emissions from wildfires on long-unburned heather moorland
5. The likely impact of climate change on 1-4 above.

1. Net carbon emissions from heather moorland managed for grouse by muirburn

When muirburn takes place, carbon is released into the air, largely as carbon dioxide, as the vegetation burns. Much of this carbon will be regained as the vegetation re-grows. A regularly patch-burned grouse moor may therefore be carbon-neutral overall if carbon is not lost from the soil. This may happen through erosion of soil by wind or water or through direct burning, or drying out and subsequent decomposition, of peat or other organic matter.

A well-managed fire on a well-managed moor will be planned for a time when the moss and litter layers underneath the heather canopy, as well as the soil itself, are wet. This will ensure that the moss and litter layers will not be consumed by the fire and any peat or other organic matter underneath will not dry out, catch fire, or erode. These conditions are more likely during the legal burning season in winter /spring than during the summer. Such burns are sometimes termed 'cool' burns. Well planned burns on well-managed moors, carried out under suitable weather conditions and according to best practice should, therefore, result in minimal loss of moss, litter, peat or other soil organic matter through burning, decomposition or erosion. It is also likely that the cover, and growth, of bog mosses will not be affected so there will be little or no reduction in peat formation and carbon sequestration by bogs. Under these conditions, managed grouse moors are likely to be carbon neutral or even have negative net carbon emissions. It has even been suggested that regularly burned blanket bogs may sequester more carbon than do less frequently burned bogs, or even possibly than unburned bogs, through the conversion of vegetation into charcoal, which does not easily decompose (25). The evidence for this is disputed however (26, 27).

By contrast, if a fire on a blanket bog takes place when the ground is too dry, which is more likely to be the case if the bog has been drained, the mosses may be killed due to further drying out of the soil after burning. This may lead to a reduction in the amount of peat laid down and carbon sequestered by the bog (18, 19). The drying out of soils, coupled with the likely subsequent increase in the cover of flammable heather, also increases the risk that subsequent burns, whether managed or uncontrolled, will ignite the peat. If fires do burn into the peat, large stores of carbon will be lost and the ability of the vegetation to recover will be compromised. On drier heathlands, if a fire has been severe enough to remove the moss and litter layers, it will result in the drying out of the underlying soil. This, in turn, will lead to decomposition of soil organic matter and exposure of the soil to the elements potentially leading to soil erosion. The dissolved organic carbon and eroded soil resulting from these processes are likely to be washed into waterways (19). Not adhering to best practice by burning on thin soils, steep slopes, or at high altitude is also likely to lead to a loss of vegetation cover and a resultant loss of carbon through decomposition and soil erosion. Similarly, burning of areas of scrub and woodland is likely to result in a loss of stored carbon. Burning more often than is recommended will lead to a reduction in the biomass of vegetation, hence also in the amount of stored carbon both above and, if root biomass also declines, below ground. Adherence to best practice is therefore critical to maintaining a neutral carbon balance.

It is not known to what extent muirburning for grouse in Scotland follows best practice since no monitoring is carried out (28). It has been estimated, however, that between 2001 and 2011, 40% of the area of land burned for grouse in Scotland was on deep peat (with a peat depth of more than 50 cm) (13) despite it being against best practice to burn such peatlands at that time if the ground cover of heather was less than 70% (14). Burning was also cited in 2019 as a damaging pressure on 32% of the 76 dwarf shrub heath features and 24% of the 71 upland bog features present within Scotland's Special Areas of Conservation (7). This suggests that best practice is often not followed. Furthermore, there is observational evidence of muirburns for grouse that have been too large in extent or have taken place in inappropriate places including: on deep peats, adjacent to trees; in wooded and scrubby areas; next to watercourses; on thin soils or summits or where there are nest sites of ground nesting birds (29). All of these contravene best practice guidance (14). Regular monitoring of burning frequency is also not carried out so it is not known how often burning of grouse moors in Scotland is carried out more frequently than is recommended. If large areas of managed grouse moor are subject to such burning practices, as the available information suggests they may be, then muirburning for grouse is likely to be causing considerable carbon losses. To determine the extent to which this is occurring, comprehensive monitoring and analysis of muirburning needs to be carried out on a regular basis.

2. Net carbon emissions from long-unburned heather moorland

When burning stops on heather moorland that overlies undrained deep peat, it is likely that the most recently burned patches will become re-wetted within ten years of burning stopping (30). If a bog has been drained and burned, the vegetation may have become dominated by heather. In this case, there may need to be a decrease in heather cover and an increase in the cover of bog mosses before peat formation re-starts and carbon sequestration outstrips carbon emissions (31). Even if burning stops, drains will normally also need to be blocked to allow the water table to rise sufficiently for this to happen (32). Although there may be an increase in the methane emitted from re-wetted bogs as the water table rises, carbon emissions via this route are likely to be small compared to the carbon that is being sequestered in the peat (32). Once peat formation re-starts, a re-wetted blanket bog should continue indefinitely to sequester more carbon than it emits. Scattered, stunted trees may, in time, start to appear if burning stops, creating a 'bog woodland' habitat (20). The trees' stunted nature means that they will not interfere with the bog's ability to form peat and so capture carbon.

Unburned dry and wet heathland that is not subject to wildfires will store an increasing amount of carbon as heather biomass, litter and

soil organic matter build up over time (33). Such areas are therefore net carbon sinks. Eventually, trees and shrubs may start to colonise the drier heaths if grazing levels are low enough and there is a seed source. Trees will gradually dry out the soil and deciduous trees and shrubs will increase the amount of available plant nutrients in the soil, making it more biologically productive (34). Both of these processes are likely to lead to increased decomposition of peat and other soil organic matter thereby increasing carbon emissions (35). Over time, however, more carbon will be sequestered in the trunks, branches and roots of the growing trees, and in the soil, leading to net carbon sequestration (24, 36). Where soils have a high organic matter content, it may be several decades before this happens (11). Mature woodlands store considerably more carbon than do heathlands (33), however, and continue to capture carbon in the soil even after maturity (24, 33). This will be true even if some timber is removed, as long as it is extracted with minimal soil disturbance and is used for long-term purposes, such as construction.

3. Area of heather moorland likely to be burned by wildfires if management burning stops

The impact of stopping muirburning for grouse on the area of heather moorland that would be subject to wildfires depends on how this change would affect, firstly, the chance of ignition and, secondly, the size of any resulting wildfires.

Chance of ignition

If all management burning of moorland in the Scottish uplands, for both sheep and grouse, were to stop then it is possible that more than 60% of the ignition sources of wildfires in moorland areas would be removed (see 'Wildfires' above). Management burning is carried out for both sheep and grouse, however, so to determine the impact on moors that are currently grouse moors, information on ignition sources in these areas needs to be separated from information for other moorland areas. Most of the larger burns recorded in Scotland by the European Forest Fire Information Service (EFFIS) in the last ten years have occurred in the north and west of the country where there are no grouse moors (Figure 2). In the regions where management for grouse takes place, EFFIS recorded only three large wildfires in the last ten years (Figure 2; Box 1). This indicates that, although wildfires do occasionally occur in landscapes managed for grouse, they are rare, especially considering the many thousands of management burns that are likely to be carried out every year in grouse moor areas (37). This rarity may be because moorland managers generally ensure that prescribed burns are undertaken when conditions are most suitable for keeping burns under control i.e. when heather moisture content is relatively high and there is little wind. It may also be because they are appropriately equipped, and trained, to carry out controlled burning and so rarely allow fires to 'escape'. Controlling fires on grouse moors may also be aided by the low levels of flammable biomass on previously burned patches. This can help to slow the spread of fires across landscapes so making them easier to control (G. Matt Davies pers. com.). If controlled burns do 'escape' they can burn large areas, as evidenced by the large 2019 wildfire in Moray (Figure 2). This may be a greater risk where the fire burns into unmanaged heather moorland. The area burned by the large 2019 wildfire, although it contained a small area of managed grouse moor, was largely dry heath and bog that was not managed for grouse. The potentially high biomass of heather in these areas may have allowed the fire to spread quickly and so may have contributed to the large size of the burn.

Box 1. Mapping wildfires in the grouse moor regions of Scotland.

The European Forest Fire Information Service (EFFIS) uses satellite images to map burned areas across Europe. Between 10th April 2011 and 19th September 2021 EFFIS recorded 131 burns that were apparently larger than 4 ha in the regions of Scotland where grouse moors are present (Figure 2). Burns larger than 4 ha are too large to be patch burns for grouse so might be assumed to be wildfires however almost all of these burns were recorded after late 2018 (Figure 3). At this time, EFFIS started to use images from a new satellite (Sentinel-2). This suggested either that the Sentinel-2 satellite was picking up burns that

were too small to be detected by the other satellites used by EFFIS or that areas of prescribed (patch) burning were being categorised by EFFIS as continuous burns. To determine which of these was the case, all burns larger than 50 ha that EFFIS had recorded within grouse moor regions were compared with the original satellite thermal images. This revealed that, of the 19 burns that were larger than 50 ha in size, 12 were within areas of managed grouse moor. Of these 12 burns, only three were made up of one continuous burned area (indicated in Figure 2) and so were likely to be wildfires. The other nine burns were examples of 'normal' patch burning for grouse. Two of the continuous burns were relatively small at 62 and 73 ha however the third was extremely large at 2,717 ha (Figure 2).

Most fires in the grouse moor regions of Scotland occur in February, March and April i.e. during the legal burning season (including the two week extension that is allowed with land owner permission; Figure 4). At this time of year there can be periods of dry, sunny, but cold weather when the moisture content of heather can drop rapidly, making it very flammable (38). Nevertheless, the small number of wildfires occurring in grouse moor areas suggests that, as well as management burns rarely escaping control, large wildfires started by recreational countryside users are also rare at this time of year. The small number of burns recorded by EFFIS in summer (Figure 4) also suggests that recreational countryside users rarely start large wildfires in grouse moor areas since more people visit rural areas in summer than in spring (Figure 5). Visitor numbers are highest in July and August (Figure 5) but no burns at all were recorded by EFFIS in grouse moor areas in these months between April 2011 and September 2021 (Figure 4). This is despite prolonged dry, warm periods occasionally occurring at this time of year and temperatures being, on average, higher than in April.

Summer wildfires do, however, sometimes occur as evidenced by a wildfire that started near Aviemore in the Cairngorms National Park in July 2006 after a prolonged warm, dry period (17). This fire is thought to have been started by sparks from a vehicle fire (17). Some wildfires are also undoubtedly started by recreational countryside users (16) and this source of ignition is likely to be the main cause of wildfires if managed burning in grouse moor areas stops. At the National Trust for Scotland's Mar Lodge estate in the eastern Cairngorms, the area subject to muirburn has been limited in extent for the last twenty years and muirburn has not taken place at all since 2016 (R. Luxmoore pers. com.). During the last twenty years there have been seven significant fires, six of which were started by recreational countryside users (S. Rao, pers. com.). Two fires required a helicopter to extinguish them, the others being small and easily put out. The three biggest fires, that were all started by recreational countryside users, occurred in May, June and July. Mar Lodge estate has a larger number of recreational users than do many other upland estates so numbers of wildfires started accidentally by recreational users are likely to be higher than at many other sites in grouse moor areas (S. Rao, pers. com.). This demonstrates both the potential for wildfires to be started by recreational countryside users but also the possibility of controlling the resulting fires.

Size of resulting wildfires

The high biomass of tall, flammable heather on long-unburned drier heather moors means that individual fires will, on average, travel faster and so have the potential to be larger than those on managed heather moorland unless they are detected and brought under control quickly or stopped by fire breaks. By contrast, the limited fuel present on the recently burned patches of a managed grouse moor acts to slow down the spread of fires making them easier to control and limiting their extent (G. Matt Davies per. com). If prescribed burning for grouse were to stop, the risk of wildfires could be reduced by putting Increased effort into fire detection and response capability, prediction of fire risk and informing the public about the risks of wildfire. The risk of wildfire can be especially high in late winter /early spring during periods of dry, sunny, windy and cold weather when the moisture content of heather can drop rapidly making it very flammable (38). Anti-wildfire measures would therefore need to consider wildfire risk in late winter /early spring as well as in summer. The risk of damaging wildfires could also be reduced by adopting measures that reduce the ground cover of heather and encourage the spread of less flammable ground layer species. Blocking of drains on peat bogs is a particularly important measure since deep peats cover a large proportion of the area of land managed for grouse (13). Other measures that could be considered for areas most at risk of wildfires

include: planting of broadleaved trees and shrubs, grazing with cattle (39) and /or mechanical cutting and mulching of tall heather (40). The use of prescribed burning to reduce the amount of flammable material at such sites could be considered but this runs the risk of accidentally starting wildfires, prevents the transition to a less flammable vegetation type and would have to be carried out regularly. As such, the other measures are likely to be more suitable in most cases. Where deer or sheep densities are high when burning stops, grazing may help to keep the heather short. If woodland expansion is wanted, however, deer and sheep numbers will need to be low. Cutting of firebreaks, with removal or mulching of cut vegetation, or controlled burning of firebreaks around the most sensitive or vulnerable areas may also be a useful method of reducing the extent of wildfires.

4. Net carbon emissions from wildfires on long-unburned heather moorland

Unburned, and undrained, blanket bogs tend to have a low cover of heather, a high cover of bog mosses and a high water table (18). Any fires starting on such intact bogs are therefore unlikely to burn into the bog moss or peat layers even under drought conditions (41). Drained bogs, by contrast, tend to have a lower cover of bog mosses and a higher cover of taller heather, particularly if they have also been burned (42). It may take around 5-10 years after blocking of drains and the cessation of burning before the bog mosses recover and heather cover declines (18). During this recovery period, there may be a build-up of dead heather that will increase the amount of flammable material. This may make the bog more susceptible to the damaging effects of wildfires, especially during spells of warm, dry weather. Fires at these times may burn into the moss layer and also into the peat. This phase should, however, be relatively short-lived since, over a number of years, the dead heather will either decompose or will be grown over by bog mosses. On bogs where purple moor grass has become dominant and is growing in large tussocks, the risk of severe wildfires during the transitional phase may be as high, or higher, than that on heather dominated bogs since purple moor grass is deciduous. As a result, in early spring the tussocks consist entirely of dead, highly flammable material that is in contact with the peat below. The spring conditions that result in purple moor grass tussocks completely drying out are currently not known. Bogs dominated by purple moor grass are, however, more common in the west of Scotland and most grouse moors are in the east (Figure 1), so this is not a major issue for unburned grouse moors.

When managed burning stops on drier heather moorland, including drained bogs, before the transition to scrub, woodland or a more diverse heathland has occurred, the height and cover of heather is likely to increase. It is possible that this build-up of highly flammable material will mean that any accidental fire will produce more heat, and possibly burn for longer in any one area, and so may be more likely to result in the moss and litter layers burning and possibly also the peat being ignited. Conversely, areas of tall, unburned heather moorland usually have a deep layer of moss which is shaded by the heather canopy. This may keep the moss and litter layers moist under all but the driest conditions and so will protect the underlying peat, even if an intense wildfire has burned the heather canopy. It is also possible that fires will spread quickly through the highly flammable uppermost shoots of the heather, especially when it is windy, but will not move down the thicker, living stems that need a higher temperature to ignite (43). The fire may therefore be kept above the ground and will not set light to the moss and peat layers below. There is very little information on the characteristics of wildfires on unmanaged dry heather moorland in different weather conditions so it is not currently possible to predict the conditions that are likely to lead to a wildfire burning into the moss, litter or peat layers (16). This lack of information is due both to the lack of areas of long-unburned dry heather moorland and to the potential difficulty of controlling burns in areas with a high heather biomass. It may not be necessary to conduct controlled burns in areas of long-unburned heather to gain this information, however, since simply recording the moisture content of the moss and litter under areas of long-unburned heather under different weather conditions may be sufficient to enable predictions to be made (44). Due to the current lack of information, it is not possible to state with any certainty that wildfires on long-unburned heather moorlands

are more likely to burn into the moss, litter or peat layers than are management fires on regularly burned grouse moors.

In the longer-term, unburned heather can become susceptible to dry, cold conditions and to heather beetle attack, both of which can lead to large areas of heather dieback (21, 22, 45). This is likely to lead to invasion by other, less flammable, dwarf shrub species (45). The same change is likely to occur after a wildfire in a long-unburned stand of old, 'leggy' heather if it has not burned into the moss, litter and peat layers, since other dwarf shrub species are better able to resprout after a fire than old heather (45). Some heather seedlings may germinate after such a fire but these are often likely to be out-competed by other plant species that are re-sprouting from underground roots. In the long-term, perhaps several decades, unmanaged heather moorland is therefore likely to become less flammable than the managed grouse moor it has replaced even if a wildfire occurs after the heather has become tall. At some sites, juniper, gorse, broom or non-native Sitka spruce may colonise, all of which are highly flammable. Gorse and broom are transitional shrub species, however, that will in time be replaced with tree species. Furthermore, gorse, broom and juniper can protect young trees from grazing animals and the former two species fix nitrogen in the soil. Both of these traits will help to foster the transition to woodland (46). Juniper regeneration is unlikely to be extensive since, at many sites in Scotland, juniper does not currently regenerate well due to unsuitable management and, more recently, the disease *Phytophthora austrocedri* (47). Sitka spruce, a species from North America, is the most frequently planted tree species in commercial conifer plantations in Scotland. It has a high ability to colonise new areas partly because it is unpalatable to deer. Colonising Sitka spruce trees may increase the flammability of unburned heather moorland. For this reason, where high numbers of young Sitka spruce trees are present, they should be removed from sites where wildfires are considered to be a risk.

If there is a seed source, and if the grazing pressure is not too high, colonising deciduous shrubs or trees will create scrub or woodland. These vegetation types do not burn easily and can, instead, act as fire breaks (16). Naturally regenerated Scots pine woodlands will also, if grazing pressures are not too high, have a high component of deciduous tree and shrub species so they, too, can be resistant to wildfires. Pine woodlands with a high ground cover of heather will, however, burn readily but, as with long-unburned open stands of heather, they will have a deep layer of moss that is likely to remain moist under most weather conditions and will protect the peat layer from burning. This protection of the peat by the moss layer was observed to occur during wildfires in Scots pine woodland with a tall heather understory at Mar Lodge estate in the eastern Cairngorms (S. Rao, pers. com.). Where there is no heather canopy or moss layer, such as where there is an ants' nest, dead wood on the ground or where tree roots are exposed, the fire may burn deeper into the peat. Although these deeper burns are likely to be localised in most woodlands, this may be a bigger issue in old woodlands that have a large amount of dead wood.

5. Impact of climate change

Climate change is expected to lead, in Scotland, to warmer, wetter winters and warmer, drier summers (48). There is also likely to be an increased incidence of extreme climatic events. Dry lightning may become a less rare event in summer than it is currently so may become an occasional ignition source. Since we cannot predict with any certainty how stopping prescribed burning for grouse will affect the frequency of wildfires, their severity or their total area, it is not possible to predict the influence of climate change on this. However, it is likely that, if the predictions of climate change are correct, conditions suitable for wildfires will occur less often in late winter /spring, when most wildfires currently occur, and more often in summer. The increased frequency of extreme weather events may also mean that there will be occasions when the threat of wildfires will be very high. Despite this, the risk of damaging wildfires is likely to remain very much lower than that in other parts of the World where there is a major problem with wildfires e.g. Greece, Australia or California. Comparisons with these parts of the World are not valid since these areas are considerably hotter and drier, especially in summer, than Scotland is likely to become in the next several decades, especially considering the increase in winter rainfall that is projected for Scotland (48). The tree and /or scrub canopy and the vegetation understory and litter layer in such wildfire-prone areas are usually also highly flammable when dry. By contrast, most vegetation types that

can occur in the grouse moor areas of Scotland, other than transitional heather monocultures, are not as flammable. Even heather monocultures, although flammable, will not burn as intensely as does the vegetation found in these other parts of the World. It is unlikely that Scotland's climate will change in the foreseeable future to the extent that the dominant vegetation types will become more like those currently seen in these most wildfire-prone areas.

Conclusion

While muirburning for grouse that is carried out according to best practice may be carbon neutral, it is likely that, every year, a considerable area of grouse moor is burned in a manner that does not adhere to best practice. This has the potential to cause large losses of carbon into both the atmosphere and the river system. In contrast to even well-burned grouse moors, unburned grouse moors can sequester large amounts of carbon, especially if drains on peat bogs are blocked and deer and sheep numbers are brought down to levels that allow trees and shrubs to naturally regenerate. Current evidence suggests that it is unlikely that severe wildfires i.e. those burning through the moss, litter or peat layers, would occur over large enough areas to counterbalance the carbon sequestered in this way, especially if wildfire prevention and mitigation strategies are adopted. Climate change may increase the risk of wildfires in summer but may also reduce the risk in late winter /early spring when most wildfires currently occur. The evidence that is currently available therefore indicates that it is more likely that stopping muirburning for grouse would lead to decreased, rather than increased, net carbon emissions and that this is unlikely to be affected by climate change, at least in the next several decades. The claim that prescribed muirburning for grouse is preventing wildfires that would cause net carbon emissions to increase is therefore not supported by current evidence.

Key knowledge gaps

To allow more reliable predictions of the impact of stopping muirburning for grouse on net carbon emissions, further information is needed in the following areas:

1. Extent to which muirburning for grouse adheres to legal burning requirements and to best practice.
2. Carbon consequences of not following muirburn best practice.
3. Relative importance of management burning, and other factors, as wildfire ignition sources.
4. Fuel moisture content of the moss and litter layers in long-unburned heather moorland under different weather conditions.
5. Weather conditions under which wildfires are severe in long-unburned heather moorland.
6. Impact of increased public information, improved fire risk prediction and better fire preparedness and response on reducing the number, area or severity of wildfires in upland areas.
7. Impact of firebreaks, deciduous tree /shrub planting, heather cutting and cattle grazing on reducing wildfire extent and severity.

Pentlands burning, 20.03.2022. Photo Credit, Ian Stevenson

Figure 2. Burned areas mapped by the European Forest Fire Information Service (EFFIS) in mainland Scotland between 10th April 2011 and 19th September 2021 using satellite images.

Note that most of the smaller burns were recorded in 2018 -2021 after data from the Sentinel-2 satellite were included in the analysis. This provided an improved ability to pick up smaller burned areas. Almost all of these smaller burns proved to be areas of prescribed burning. Arrows indicate the location of burns of more than 4 ha in size situated within areas of patchwork management burning where the burned area covered the whole mapped polygon. These burns can be assumed to be wildfires started on managed grouse moors.

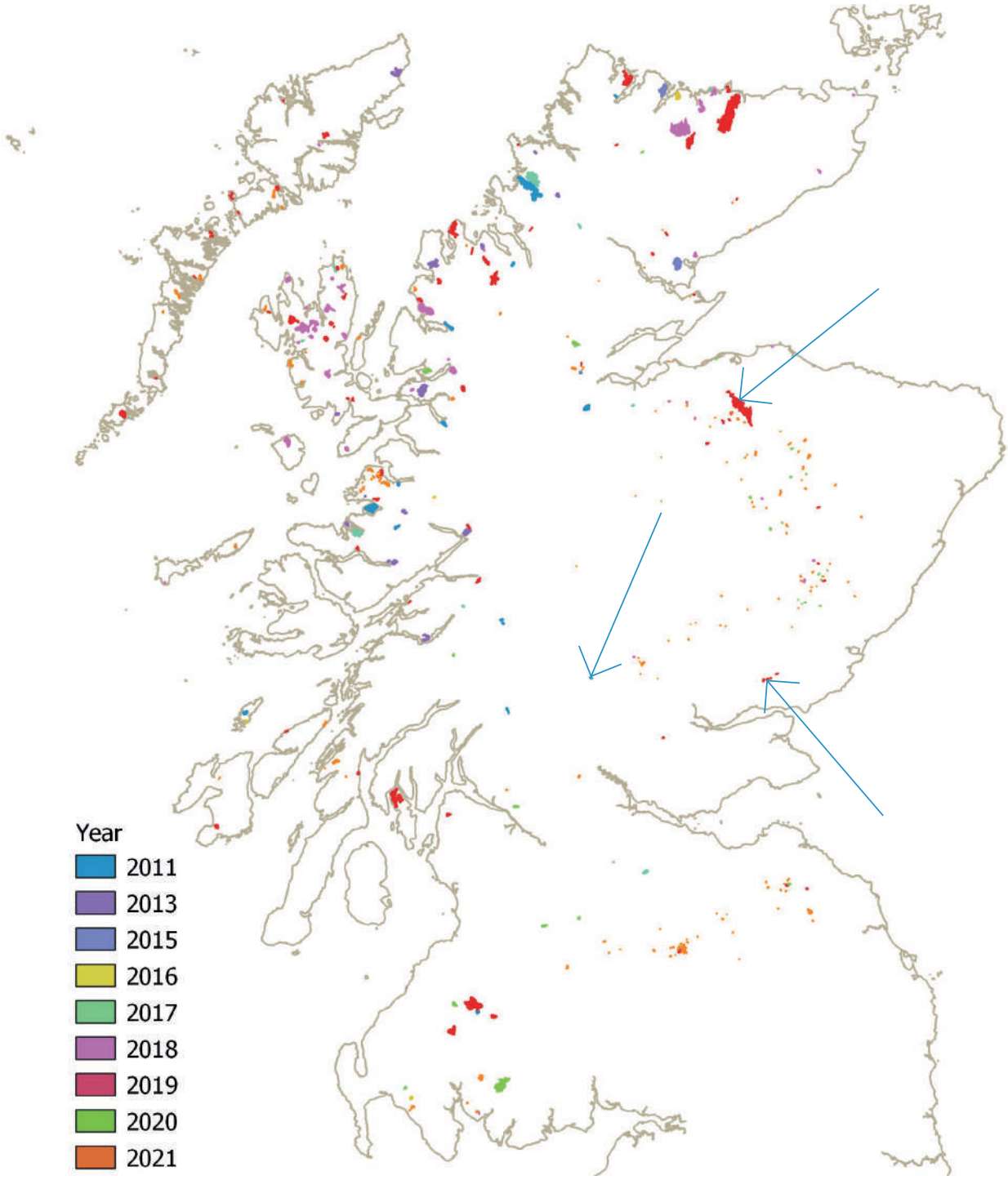


Figure 3. Number of burned areas in different size classes in each year between 10th April 2011 and 19th September 2021 as mapped by the European Forest Fire Information Service (EFFIS).

EFFIS burn data are based on satellite data (Modis and, latterly, Sentinel-2). Data are for: Aberdeen City and Aberdeenshire; Angus and Dundee City; East Lothian and Midlothian; Inverness & Nairn and Moray, Badenoch & Strathspey; Perth & Kinross and Stirling; Scottish Borders. The increase in the number of relatively small burns recorded in 2018- 2021 is due to an increasing use of images from the Sentinel-2 satellite at that time (R. Boca, pers. com.). Since most of these proved to be areas of prescribed burning, this does not represent an increase in the number of wildfires.

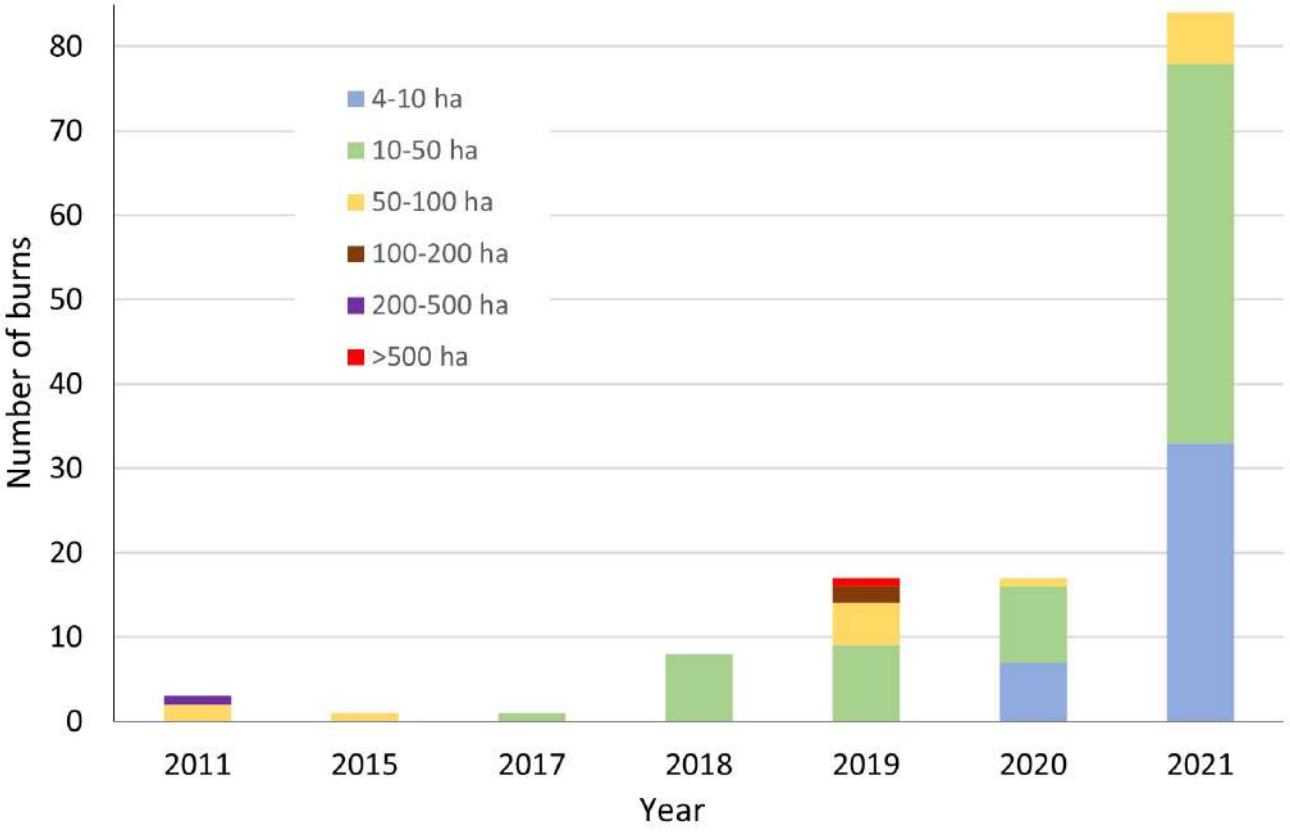


Figure 4. Number of burned areas in different size classes in each month between 10th April 2011 and 19th September 2021 as mapped by the European Forest Fire Information Service (EFFIS).

Data are for: Aberdeen City and Aberdeenshire; Angus and Dundee City; East Lothian and Midlothian; Inverness & Nairn and Moray, Badenoch & Strathspey; Perth & Kinross and Stirling; Scottish Borders.

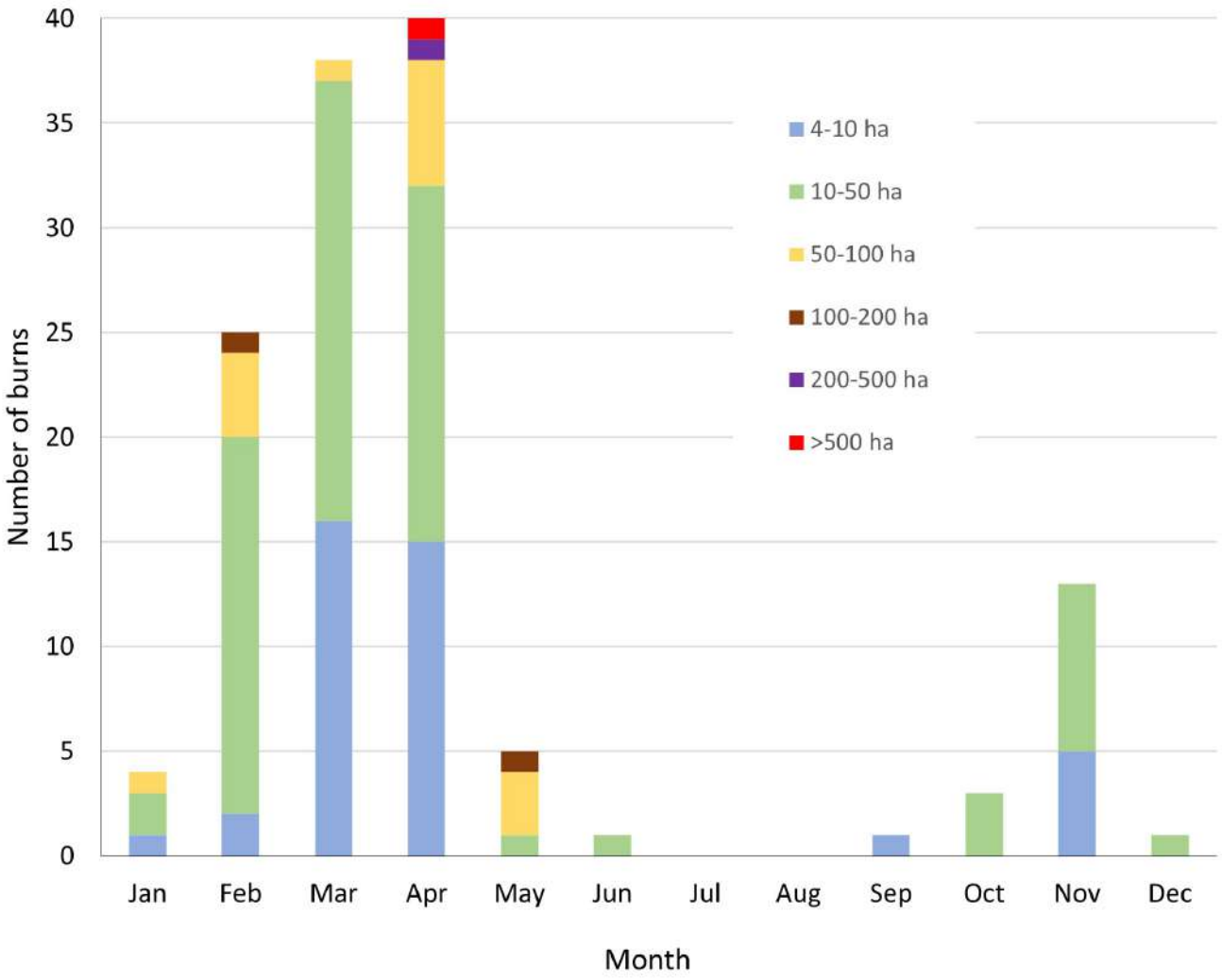
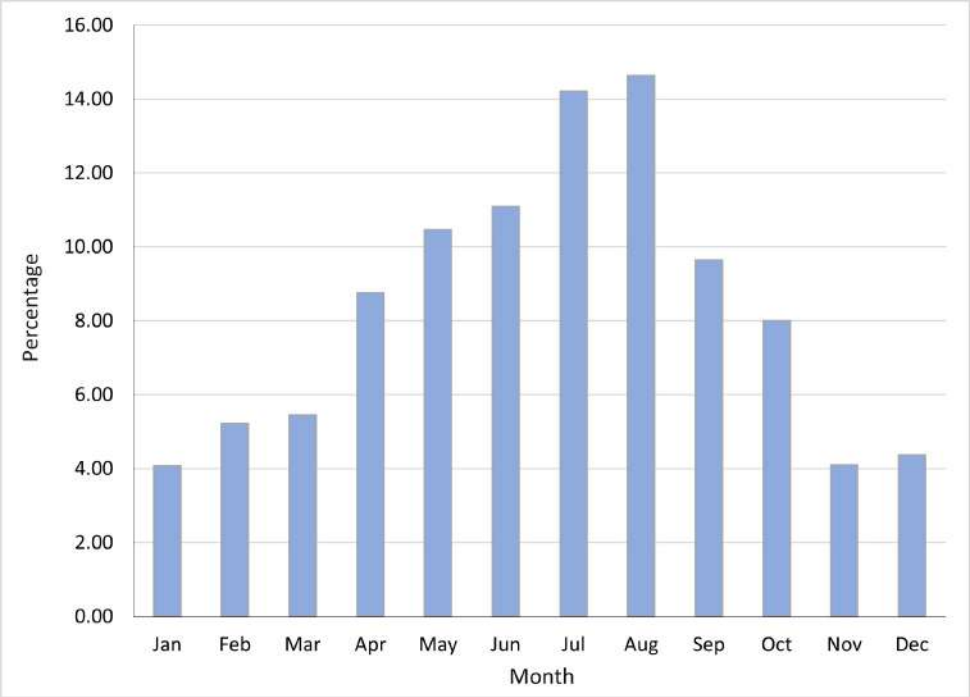


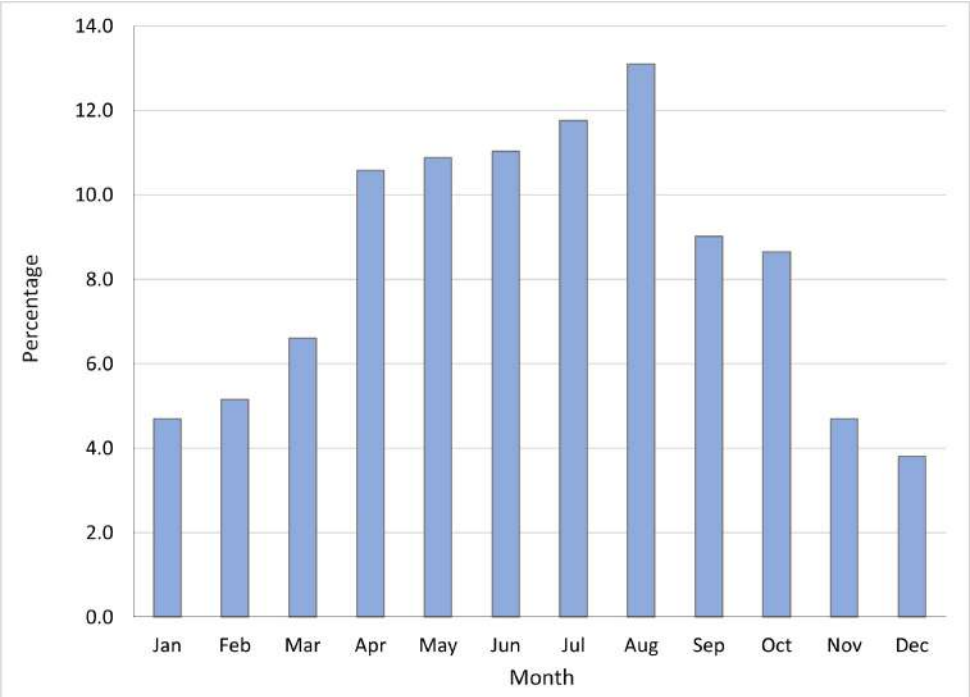
Figure 5 a) Percentage of the total number of visitor days recorded in each month for the Cairngorms National Park between 2009 and 2019 inclusive b) Percentage of the total number of visitors to Abernethy estate in 2009 and between 2011 and 2018 inclusive.

Data kindly provided by the Cairngorms National Park Authority and the Royal Society for the Protection of Birds respectively.

a)



b)



Other benefits of reducing muirburning for grouse

Carbon balance is not the only factor that needs to be considered when comparing the impacts of managing heather moorland for grouse with those of leaving the moorland unburned. Stopping burning on blanket bogs, especially when combined with blocking of drains, may result in improved drinking water quality (fewer suspended particles and lower iron and aluminium levels), may reverse changes to stream invertebrate communities that are associated with burning on blanket bogs (49) and may reduce flooding downstream after very heavy rainfall events (30).

The limited information that exists on nutrient budgets on burned heather moorland suggests that there will be net losses of phosphorus, and perhaps potassium, each time the heather is subjected to even a 'cool' burn (50) but no work has been done to estimate what effect, if any, this might have on plant growth rates. Any nutrient losses are likely to be greater if burns are hot, if they are very frequent and /or if erosion is caused (50). Stopping muirburn may, therefore, of itself, prevent this loss and lead to a slow increase in the amount of phosphorus, and perhaps potassium, in the soil. This would lead to more productive soils and potentially a higher vegetation biomass that stored more carbon.

Allowing drier heather moorland to transition towards woodland and scrub can not only make the vegetation less flammable if other plant species are able to colonise the heather monoculture, it also provides a wide range of other benefits (7, 51, 52). As the habitat and structural diversity increase, so will biodiversity. Soils will become more porous and able to store more water, and trees and shrubs will intercept rainfall that will then evaporate thereby alleviating flooding further downstream. Tree and shrub roots will hold soil in place preventing landslips. Nutrients and dissolved organic carbon will be held in the soils, keeping streams clear and clean. The clean water will benefit fish as will the input of nutrients from deciduous tree leaves falling into streams and the shading of streams in summer. Nutrients brought to the surface by the deep roots of deciduous trees will improve soil productivity. Although the increasing productivity of the soils will, in many cases, cause net carbon emissions for the first decade or more as soil carbon decomposes, after this time, the woodland will store considerably more carbon than did the precursor heathland (33).

Encouraging a transition to a more wooded landscape would also improve the potential for a more diverse range of economic outputs from the land. Domestic stock and wild deer would have access to improved forage and shelter and there would be a wider variety of wild game, including grouse. Timber products would also be available as would non-timber forest products including nuts, berries and craft materials. Fisheries would be improved. Additionally, a more wooded landscape hosting a wider variety of habitats as well as plant and animal species, and providing a wider variety of outputs, would be more resilient to both climate change and novel pests and diseases. The change to a more wooded landscape would therefore provide numerous benefits for both local communities and the wider population of Scotland as well as helping to tackle biodiversity loss and climate change (7).

Achieving the benefits

To achieve all the benefits of reducing muirburning for grouse, the woodland and scrub that replaces areas of managed dry heather moorland will need to be made up of mixed, largely deciduous, tree and shrub species. To minimize carbon losses from the soil, new woodlands should be established through natural regeneration or using minimal soil disturbance methods (53). Additionally, where they are to provide a timber output, they should be managed on a continuous cover basis using methods that minimise soil disturbance. To bring about widespread woodland and scrub expansion, deer and sheep numbers will need to be brought down to levels that allow trees to regenerate without the need for fencing or other protection. Drains on deep peats will need to be blocked to allow water tables to rise. This will increase the carbon and biodiversity benefits of reducing burning on deep peats and reduce the risk of wildfires burning into the peat during droughts (41).

A first step towards achieving a reduction in the areas of burned grouse moor might be to ensure that all muirburning adheres to best practice. Regular monitoring of muirburning practice across the whole of Scotland could be used to underpin the planned muirburn licencing scheme (54) where the granting of the licence was dependent on adherence to best practice. Much of the muirburn monitoring could be undertaken using satellite imagery to map burns. The granting of licences might also be linked to management actions that would reduce the risk of wildfires occurring. A significant reduction in the area of burned moorland might also be achieved by allowing muirburn to take place only where there is a clear biodiversity benefit. This would achieve many of the benefits of reducing muirburning whilst also ensuring that areas of managed dry heather moorland were maintained for their cultural and biodiversity value (55). Burning of such areas could be encouraged, if necessary, through grant aid.

Recommendations

Some key Government actions would help to resolve the current debate surrounding muirburing for grouse and carbon balance as well as helping to reduce the most damaging effects of muirburning and wildfires. These are:

1. Make adherence to best practice a condition of granting a licence for muirburning and /or limit muirburning to areas where there is a clear biodiversity benefit,
2. Fill knowledge gaps to allow better predictions to be made of the carbon impacts of stopping muirburning for grouse.
3. Carry out research aimed at improving wildfire prediction, education, detection and mitigation measures.
4. Continue to encourage blocking of drains on blanket bogs and encourage other measures that reduce wildfire risk where this is thought to be high.

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