Land-use and carbon management: can new fire prescriptions, education and training minimise conflict for the management of heather shrubs in the United Kingdom?

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Abstract
Important carbon stores in the United Kingdom are found in peat soils underneath areas of heather and grass moorland. Traditional land-uses in these areas have been grazing by livestock and used as hunting areas. Fire is used to regenerate heather (*Calluna vulgaris*) and grasses and to create habitat mosaics to support the valuable hunting bird the red grouse (*Lagopus lagopus scoticus*).

International agreements on carbon management are gradually being brought into national laws and strategies. However carbon pathways are complex and there is insufficient research to directly support simplistic application of the carbon strategies in all cases. Can land managers and prescribed fire operatives still develop techniques that minimize the impact on carbon budgets?

We discuss how the application of prescribed fire principles and processes, coupled with fire danger rating systems, good practice guides and competency-based training systems might give support to land managers to incorporate appropriate carbon management strategies and the uncertainties that remain to be resolved by further research.

Keywords: Muirburn, prescribed burning, fire danger rating, blanket peat, grouse moor

1. Introduction

Moorland management in the upland and mountain areas of the United Kingdom (UK) has had a variety of policy and market influences over the last 50 years. Traditional economically-based land-uses of livestock grazing and game shooting (hunting) still dominate. However the context has changed dramatically in the last 10 - 20 years with the increasing focus on biodiversity objectives and on the problem of climate change, carbon budgets and pressure to reduce carbon emissions.

Fire is a key land management tool for managing moorland vegetation. Burning moorland is a visually dramatic event that emits significant quantities of carbon to the atmosphere. However over the whole disturbance and recovery cycle it is not so clear because carbon pathways are complex. Also the scientific knowledge base is struggling to provide the information required by policy makers. With hotter and drier summers associated with climate change, there are increasing risks of wildfires sufficiently severe to threaten the significant carbon stocks held in the soil as peat.

In addition a combination of reduced grazing by livestock and substantial afforestation programmes using natural regeneration techniques is leading to increased fuel loads across wide areas (Bruce, 2003). This combination of increased fuel loads and fuel continuity is leading to higher fire intensities and larger fires. There were a significant number of landscape-scale fires in the spring of 2003 and most recently this spring, 2011. The elevated fire intensities and large areas burning are also likely to increase the potential for ignition of smouldering ground fires. In addition to the immediate costs of extinguishing these fires and damage to property and infrastructure, there can be prolonged loss of income from the land, significant loss of biodiversity and lasting damage to the environment and ecosystem services. In this paper we focus on the impacts of fire on carbon stocks and carbon sequestration of peatland ecosystems.

Prescribed burning could reduce both the hazards and risks from wildfires. Should new objectives and constraints be built into land and fire management objectives to take account of the new concerns over carbon emissions and wildfire risks? Can good practice guides be revised, fire danger rating systems introduced and new training programs initiated? If changes are to be introduced without significant conflict over the potential negative economic and social impacts then there will need to be confidence in both the science and the mitigation measures introduced to reduce carbon emissions and wildfire risks, as well as sensitivity in their application.

2. Peat carbon stores

There are many different of estimates of the areas of different moorland habitats and the soils storage of carbon in the United Kingdom using different survey methods and criteria for definitions. Work on carbon issues in the UK, including information gathering, is increasingly being carried out at the level of the devolved administrations of England, Scotland, Wales and Northern Ireland. There are therefore some differences in the information base.

The definition of blanket bog is generally accepted as: areas of semi-natural vegetation over-lying peat of at least 0.5 m depth and forming a blanket over moderately sloping ground (NCC 1990). The area of blanket bog in the UK has also been estimated at 1.4 million hectares and the UK holds 10 – 15% of the total world area of this habitat (Lindsay, 1995). Scotland, with around 1 million hectares, holds the majority of this resource.

The difficulties of estimating the amount of carbon stored in peats is discussed by Chapman et al. (2009) and estimates vary widely. However, soil carbon information collected as part of the ECOSSE report (SEERAD, 2007) indicated that the organic soils in Scotland contained 2,735 Mt of carbon and in Wales 196 Mt. This does not include carbon found in mineral soils. The estimate of carbon held in surface vegetation, including forests, by comparison is only 118 Mt for the whole of the UK. This indicates that the substantial carbon stocks are held on a relatively small area of land and it is therefore clear that organic soil carbon deposits are a very important carbon store in the UK.

The initiation of blanket peat formation happened in periods of cooler and wetter climate, 2300 – 7000 years ago (Simmons I, 1990). There is some evidence that this may have been associated with early agricultural systems that used burning, grazing and shifting agriculture, causing paludification which prevented tree regeneration. Charcoal provides evidence of occasional fires throughout their history but, none the less, peat has continued to accumulate, to a depth of over 3 m in many places. More recently human induced climate change towards a climate with warmer wetter winters and drier hotter summers could threaten the area of bog habitat in upland areas through drying and erosion. Also, even though the climate is generally wet, shorter-term weather patterns can create droughts which dry out peat fuels and make them available to burn. All that is then required is an ignition source for a ground fire to occur with the potential for massive loss of carbon to the atmosphere.

3. Traditional land-uses

The traditional land-uses for moorland areas in the uplands are grazing for livestock and game shooting (hunting). The red grouse game hunting tradition continues with market values in 2011 of £75 per bird being found for organised shoots that can achieve a total of between 100 – 300 birds per day. The capital value of a grouse hunting area is based on a 10 year average number of birds harvested per year, multiplied by a capital value of £1,750 - £2,000 (Savills, 2010). This activity supports jobs and investment in remote areas. In relation to wildfire management there are three important benefits: fuel hazard reduction, a pool of skilled and experienced fire managers and a significant quantity of specialist fire suppression equipment.

Both livestock grazing and game shooting need the surface vegetation of grasses and shrubs, often *Molinia caerulea* and *Calluna vulgaris*, to be burned on a rotational basis to remove old plants and promote young growth for grazing animals in a habitat mosaic of different ages of shrubs. Fire return intervals or rotation lengths can be as little as 10 years on fertile sites and 50 years on poor quality sites. However, largely due to a lack of resources or suitable burning days in the winter burning season, even on fertile sites the proportion of a moor that is burned annually is often around 1 - 2% (Stevenson et al., 1996) rather than the 5 – 10% normally recommended (SEERAD, 2001b). The benefit from burning carried out well comes from the nutritional value of the new shoots of young heather plants. The quality of the soil in an area will ultimately determine the nutritional quality of the heather, but on otherwise barren ground with acidic soils, the young plants can provide sheep and grouse with higher concentrations of essential minerals such as calcium, phosphorus, nitrogen, magnesium and potassium (Miller 1979). This is particularly important in late winter and early spring in the run-up to lambing and nesting seasons when fodder is otherwise at its lowest quality.

Traditional burning in Scotland known as "Muirburn" has a long history. It was first regulated by an Act of Parliament in Scotland in 1424, supplemented in 1523. There was also an Act in 1773, the long title of which is interesting: "An act for the more effectual preservation of game in that part of Great Britain called Scotland, and for repealing and amending several laws now in being related thereto". More recently the 1946 Hill Farming Act with equivalents in each part of the UK has been updated in 2007 with the Heather and Grass Burning Regulations covering England and Wales and the Wildlife and Natural Environment (Scotland) Act 2011. The various historic and new Acts have often only changed the start and end dates of the season by small amounts between October or November and March or April. However one recent change in Scotland is that the burning season can be changed by Ministers under the Climate Change Scotland Act 2009. For a land management practice with such a long history this is a very significant change.

The current burning season in Scotland is from 1st October to the 30th April, covering the winter and spring months when the soil is generally wet and soil organic matter is therefore not available to burn. Fires are normally burnt with the wind as quick surface fires. Fireline intensities can range from 75 kW m^{-1} to 3,388 kW m^{-1} (Hobbs and Gimingham, 1984, Davies et al, 2010) but in deep heather fire intensity can be as high as 15,000 kW m^{-1} (Bruce and Servant, 2004). Fire severity, even with high fire intensities is modest, because the soil is generally damp and heather habitats are relatively fire adapted and, with an appropriate fire return interval, they recover well. The relatively low severity or impact of most fires is because residence times of management fires are generally short and temperatures at the soil surface are not elevated for any length of time. If the weather is dry and relatively warm then the litter and moss layer can dry out and ignite creating more severe fires, however the lower levels of peat do not generally become sufficiently dry to burn until there has been a prolonged drought, which normally only happens in the late summer. There are situations where fires can do damage and are inappropriate; these are covered by good practice guides, in Scotland the Muirburn Code (SEERAD, 2001) and in England and Wales the Heather and Grass Burning Code (DEFRA, 2007).

4. Carbon accumulation rates

Both raised and blanket bogs can be important ecosystems for sequestering carbon from the atmosphere. Carbon accumulation rates for two blanket bogs in the UK range from 0.35 - 0.56 t ha^{-1} yr^{-1} (Billet et al., 2009) compared with estimates for raised bogs in the boreal zones of Canada (Benscoter and Wieder, 2003) of 0.23 t ha^{-1} yr^{-1} and in Finland for recently burned areas a short term accumulation rate of 0.7 t ha^{-1} yr^{-1} and with a long term accumulation rate of 0.18 t ha^{-1} yr^{-1}.

In the UK research on the carbon balance of existing burning practices is acknowledged to be at an early stage. There have been mixed results. Different studies have found either a small negative or positive long-term carbon balance from surficial burning but it is a complicated picture. So far studies have tended to be short term and only look at a small number of factors. One of the few longer-term studies (Garnett et al., 2000) looked at a variety of treatments at Moor House in northern England over a period of 30 yrs, including: unburned, grazed and the combined effects of burning and grazing. The fire return interval for burning was only 10 years. The results suggest a small net gain of carbon in the surface peat layers for all treatments (though decomposition rates in the deeper peat were not measured) on the site. The carbon accumulation rates above the 1940 horizon (including some accumulation from before the commencement of the treatments) were: unburned 1.44 t ha^{-1} yr^{-1}, grazed 1.69 t ha^{-1} yr^{-1}, and burned and grazed 0.97 t ha^{-1} yr^{-1}. The study did not separate out the effect of burning alone, nor did it collect data on longer fire return intervals. The picture is further complicated by methane emissions, a more powerful greenhouse gas than carbon dioxide. There is a suggestion that methane emissions from blanket peat may be increased shortly after a fire (Gray 2006), but reduced later (Ward et al., 2007)

5. Wildfire threat

Wildfires that ignite peat deposits during droughts can consume significant quantities of organic soils. The peat is generally not burnt by the flaming front but by the glowing, smouldering combustion, that follows behind (Wein, 1983). Various studies have looked at carbon loss rates from fires over large areas of raised bog in Canada, in the range of 21-32 t ha^{-1} (Turetsky and Wieder, 2001, Turetsky et al., 2002, Benscoter and Wieder, 2003). Carbon losses were similar in Finland at 25 t ha^{-1} (Pitkänen et al., 1999). However under very dry conditions the whole peat layer can be lost with 200 t ha^{-1} (Pitkänen et al, 1999) given as an example.

Raised bogs are found in water accumulating parts of catchments, in various climatic areas. Blanket bogs, the common type in the UK, are found in water shedding areas of catchments, in wet climatic areas. In a drought the potential is therefore that blanket bogs can lose moisture from the whole soil profile. Heather on drier, aerated peats also have deep roots that have been found to dry out the soils around the roots (Krivtsov et al., 2008), which could also make a significant part, or even the whole peat deposit available to burn. Laboratory studies also support this risk by indicating that virtually all peat was consumed up to the moisture content of extinction of smouldering fire, which in peat is high, at around 110% (Frandsen,1997) and 120% oven dry weight (ODW) (Rein et al, 2008).

An example of the amounts of carbon that can be released from a blanket bog in Scotland can be seen from data from a wildfire at Rothiemurchus, near Inverness in northern Scotland. This was a small 10-ha fire that was started on 19 July 2006 that covered an area of moorland and trees planted on drained blanket peat. Ground fires smouldered for six weeks after the initial fire run was suppressed. Information was collected on carbon consumption by the fire (G.M. Davies, unpublished data). The smouldering fire burned down about 0.25 m over around a third of the site, bulk density was 0.126 tonnes per m^3, if organic matter is assumed to be 50% carbon then soil carbon emissions are around 525 tonnes. For a small fire this is a large figure.

A historic account from the Aberdeen Journal of 5th July 1826 relates how a series of fires were probably ignited during a long summer drought by lightning strikes and burned extensive areas of north east Scotland. These fires extended to Glen Tanar and *"not only the heath but the whole surface of the hills and moss, to the depth of five or six feet* [1.5 – 2 m] *were in one mass of fire"*, and nearby in Donside: *"The flames raged with great violence and a brisk wind springing up, they soon spread along the hills for several miles, burning the peat which the inhabitants had prepared for their winter fuel, and the very uncast moss, to the depth of several feet".* Also the Moss of Cochrage: *"In a few minutes the whole breadth of the moss was in a blaze. It still continues to burn to the depth of five or six feet and will probably continue to do so till the rain and snow of winter quench it."*

One of these fires of 1826 at Strachan in Aberdeenshire was estimated to be some 7 miles by 5 miles (9000 hectares) and burned down between 5 - 7 feet [1.5 - 2.1 metres] into the peat. If the same bulk density and carbon contents are assumed, this one fire could have released between 960 – 1,344 t C ha^{-1} and a total of 8.6 - 12 Mt of carbon. These are very large amounts. If the fire burned in a more variable way like the Rothiemurchus fire where only a third of the area burned, this one fire would still have released 2.8 – 4 Mt of carbon, still very large amounts from one fire. Fires that consumed the surface peat up to 30-40 cm over large areas in the North York Moors in 1976 (Maltby et al 1990) left an eroding surface of unconsolidated peat which remains unvegetated in many areas today and will continue to erode until the complete peat profile has been lost.

6. Hazard and risk reduction

Once a peat fire is burning it is very difficult to extinguish (Wein, 1983) and can last for months (Frandsen 1991). Surface fuels carry a fire across a landscape and ground fires are often ignited behind the main fire front. The main risk reduction method must therefore be to prevent fire from reaching peat that is available to burn, or to limit the area of peat that a fire covers, when the peat is available to burn. Nearly all wildfires in the UK are human-caused. There are a number of standard administrative and educational measures to change behavior to reduce wildfire ignitions (FAO, 2006). Even where significant and successful efforts to prevent wildfires are made using such methods (Butry et al, 2010), ignitions continue. A complimentary focus on techniques to engineer out the risks through fuel reduction burning is therefore also required. It is likely that the most cost effective balance of these techniques will vary depending on the situation and location.

There are two potential strategies to reduce the fuel load hazard. The first is where there is a site with high risk of ignition, for example a campsite. The fuels between the high-risk location and the peatland can be broken up with firebreaks. The second strategy is to reduce the fuels over the whole area, including the peatland, so that fire intensity and residence times are lowered over an area.

Fire behaviour depends significantly on the height and structure of the heather canopy and high-intensity fires that are difficult to control are most likely in tall and dense heather (Davies et al., 2010). It is recognized by land managers and in the Muirburn Code that heather should be burnt when it is more than 20 cm tall to ensure good recovery (SEERAD, 2001a). Heather in upland Britain grows at between 1 and 2 cm per year depending on soil quality and grazing intensity (SEERAD, 2001b). This means that on a good quality site it will take 10 years and on a poor quality site it will take 20 years, to grow to 20 cm.

Firebreaks normally need to be two and half times as wide as anticipated flame lengths to be secure (Roberts and Attwood, 1992). Heather fires regularly achieve flame lengths of 3 m and have been known to be up to 8 m (Bruce and Servant, 2004). To cope with a 3 m flame length a firebreak therefore needs to be 7.5 m wide, and for an 8 m flame length some 20 m wide. Heather fires generally do not create significant spotting activity and firebrands and embers do not travel far. So a firebreak of 20 – 30 m would normally be adequate. Cutting can be useful as a short-term firebreak during a burning operation but the cut material and underlying moss and litter dry out quickly and therefore cutting does not break the continuity of fuels in the medium to long term.

A firebreak regime with sufficient burnt ground or ground with low heather therefore needs to have areas of vegetation that are less than 20 cm tall and a minimum of 20 m wide, at all times. This means that a new strip will need to be burnt in the firebreak area every 5 years on good ground and on poor ground every 10 years. To avoid burning each patch of ground too soon, before the heather has reached 20 cm, a minimum of 100 m wide area could suffice. This would create a fire return interval of 25 years on a good site and 50 years on a poor site. This is the theoretical minimum width. Operational constraints are likely to mean that a wider area would be required but it is still a small area in relation to the size of most heather moors or blanket bogs.

If there are a variety of directions or angles between the areas to be protected and the likely risk points where ignitions will occur then an area-based fuel hazard reduction may be required. Wind will also play a significant role in determining the direction that a wildfire develops and the wind can blow from any direction. The remoteness of the area and the length of time between a fire starting, detection and the mobilization of suppression resources will also be relevant factors. This means that a fire prevention strategy must prepare for a fire coming from any direction and the length of time needed to put any wildfire out. An area-based strategy for fuel load reduction is more likely to cope with this scenario.

For an area-based prevention strategy based on fuel load reduction to have a reasonable chance of working we suggest that a minimum of 50% of a heather moor will need to be less than 20 cm tall. Similar rotations would need to be applied to poor (50 years) and good quality sites (25 years). For each 100 hectares of moor this would create an annual burning target of 2.5 hectares (2.5%) and 5 hectares (5%) on poor and good ground respectively.

If a moor has not been burnt for some time the recommendation in the Muirburn Code (SEERAD, 2001b) is for 40% of the moor to be burnt in the first two years of a programme in order to prevent sheep from congregating on the young regrowth and preventing regeneration. However careful risk assessments and control measures will be required before starting a burning program in an area with high fuel loads. The issue of the lack of burning on some moors and the financial support mechanisms that might need to be established or improved to achieve these burning targets may need to be investigated.

7. Fire Danger Rating

The fire danger rating (FDR) process is an assessment of key aspects of the fire environment that have a major influence on the ease of ignition, rate of spread, difficulty of control and impact of wildfires (Merrill and Alexander, 1987). FDRs are also used extensively to assist prevention and detection planning, initial attack dispatching processes, prescribed fire planning and implementation and other tasks (Taylor and Alexander, 2006). The Canadian Fire Weather Index (FWI) system has been adopted and adapted by many countries, including England and Wales (Met Office Fire Severity Index – MOFSI, Marno, 2005), where it is used to control access to public land in periods of exceptional fire danger.

Although originally based on Jack Pine forest fuel types the FWI has been adapted to reflect the fire behaviour found in a number of environments (Taylor and Alexander, 2006). The soil moisture indices, within the FWI system, are called the Fine Fuel Moisture Code (FFMC), Duff Moisture Code (DMC) and the Drought Code (DC), and they reflect the moisture of the litter, duff and soil and down to a depth of 1.2 cm, 7 cm and 18 cm respectively.

Surface fires are often the ignition source of smouldering peat fires (Chistjakov et al., 1983). For forest surface fuel types there is a range of litter and soil moisture content (MC) that can support first ignition and then the rate of spread of fires. For shrub fuels there may be a more distinct threshold value, where there is no ignition below the value but then intense fire behaviour above it (Anderson and Anderson, 2009, Davies and Legg, 2011). Furthermore the MC of the shrub fuels can change independently of the MC of the litter and soil layers. This means that the MC of each fuel stratum has to be looked at independently for a fire danger rating system to be effective.

For heather the MC of ignition is less than 70% ODW but fire spread occurs at MC less than 60% of both live and dead fuels. The moss and litter layer ignites during heather fires at MC less than 140% and smouldering may continue after the flaming combustion has passed at MC less than 70% (Davies and Legg, 2011). As a comparison another common moorland shrub species, gorse, *(Ulex europeaus)* has a threshold MC for ignition of dead elevated fuels of less than 36% (FFMC 69.5); and for fire spread it is less than 19% (FFMC 82.7) (Anderson and Anderson, 2009). For a comparison of lower fuel strata MC relationships; feather moss, lichen and white spruce duff (Lawson et al, 1997) had a 0.5 probability of ignition at around MC 80 - 90%. There is some indication that the ignition point of peat is similar to some forest duff types with ignition at around 125% (Rein et al,. 2008, Rein et al., 2009).

Models have also been developed for the smouldering fire potential in the boreal forests of Alaska and northwest Canada (Lawson et al., 1997), for the duff, feather mosses, and *Sphagnum* fuel types using DMC and DC values of the FWI system. Peat was equated with the lower *Sphagnum* layer of the model. The probability of ignition at different moisture contents of these fuels was tested and related to DMC and DC. The probability of ignition was greater than 0.9 for bog vegetation types at values of around DMC 55 - 60 and DC 550. This gives an indication of the potential for DMC and DC values to be used to predict the potential for smouldering peat fires, which could help people doing prescribed burning of surface fuels over peat deposits to avoid severe fires and help those responsible for fire suppression to make appropriate preparations. Further fuel moisture research and fire tests in UK conditions would be required to calibrate the FWI system for UK fuel types.

8. Balance of risks

The risks presented here are the immediate ones comparing CO_2 emissions between low intensity prescribed burning versus high intensity severe wildfires. Other carbon pathways from heather moorland, whether from dry heath, wet heath or blanket bog have not been presented because we have insufficient information. These research needs include: the composition of smoke from prescribed burning, the distribution and role of black carbon, dissolved organic carbon (DOC) losses in water related to burning in all habitats and the role of methane.

What we do know is that there are increased risks of severe fires in peat with the climate change scenarios for warmer drier summers considered likely for the UK (Albertson et al 2009). The spatial distribution of human caused fires in summer will need to be considered with more attention given to popular recreational areas. However the continuing increase in fuel loads over large areas is increasing the hazard, because at some stage these fuels will become available to burn and will come into contact with an ignition source.

Per hectare, potential CO_2 emissions from prescribed burning are not high. There are also tools that the land manager can use to mitigate potential CO_2 emissions from prescribed burning. These include: longer rotation length / fire return intervals, patch size control, control of fire intensity by varying ignition patterns, selecting the appropriate season and weather conditions and the avoidance sensitive areas.

The mega-fire risk of massive CO_2 emissions from large severe peat fires is unknown. These are not common events. However both the number of large landscape-scale wildfires in peat areas and the frequency of difficult fire seasons appear to be increasing, for example 2003, the summer of 2006 and this spring, 2011. It would therefore seem reasonable for this risk to be given more attention and mitigation measures put in place.

Measures to improve suppression capability have been identified (Bruce, 2003) and are being undertaken under the leadership of the Scottish, English and Welsh wildfire forums at a national level and by community-based wildfire groups at a local level. However the largest and most severe fires appear to be occurring on areas where there is no prescribed burning being carried out, such as conservation areas, young regenerating native woodlands, and abandoned agricultural land. These are areas with significant, continuous and growing fuel loads. The landowners in these areas are also less likely to have specialist equipment or staff experienced with fire. A reintroduction of prescribed burning to these areas, targeted at fuel hazard reduction, is likely to improve many aspects of resilience.

9. Development of the practice of Muirburn

Legislation on muirburn has been recently updated in most of UK jurisdictions. The focus for change is now on the way that muirburn is practiced. The tools that can be used to influence burning practices include the Muirburn Code, formal moorland management plans, prescribed burn plans, education and training.

Muirburn is usually a form of unbounded burning where fires are stopped either on previously burned areas or by using fuel moisture changes over the landscape, though swipes are increasingly being used to create fuel breaks. The desired patchwork habitat mosaic for the economically valuable red grouse creates the objective of burning small patches for most land managers. The Muirburn Code in its current form supports this and identifies areas and species that should not be burnt. Formal written detailed moorland management plans are becoming a requirement on some conservation areas but there is a debate on the costs and benefits of this approach. Conservation agencies like them but land managers consider them a burden.

Prescribed burning by implication contains a requirement for a written prescribed burn plan for each fire. As a team burning heather can manage as many as 30 small fires in a day, a requirement for a written prescribed burn plan for each fire would be an impractical, costly and bureaucratic approach.

The developing carbon emissions issue and its relationship to muirburn has not been clarified by research, codified, or built into training, yet. This creates opportunities for education and awareness raising exercises. These could explain the opportunities to limit potential damage by subtle changes in approach, for example, avoiding peat fire ignition by only burning when DMC and DC values are low, promoting longer rotations, avoidance of steep slopes and vulnerable peat deposits. However as many land managers have been practicing muirburn for many years educational programs to explain the need for change and the benefits that may accrue to them, may have more chance of success than creating bureaucratic hurdles.

In the UK there are a number of not-for-profit organizations, trade associations and professional associations that provide seminars, demonstration days and educational resources. The discussion over the carbon balance of muirburn is likely to be developed through information exchange between researchers, policy makers and practitioners at such meetings and through related magazines and other media.

There are also formal competency based training courses and certification systems, which are likely to be accessed by people entering the industry. Competency standards, called national occupational standards, are developed by employers and are not likely to change until the science is clarified by research.

10. Conclusions

Smouldering wildfires could release massive stocks of carbon held in blanket peat in the UK. Systematic preventative burning by land managers under moderate conditions could protect existing carbon stocks, especially in high fire risk areas.

A change to remove a “no-burning” policy on peatlands, to one promoting appropriate preventative fuel reduction burning, is required. In some situations this will not require public investment as there is an established market economy for grouse moor areas. Burning on other areas and land-use types may need public funding.

Land management in the UK is part of the market economy and voluntary systems that minimise bureaucracy are therefore preferred over legislation. This means that a good practice guide, such as the Muirburn Code, is preferred over licensing or a requirement for prescribed burning plans for individual fires.

Information exchange in seminars, demonstration days and voluntary education and training rather than compulsory certification are more likely to generate change. If there are funds available, this is where the money should be spent.

Further research is needed into carbon pathways, including carbon fixation across the whole fire cycle. Also fuel moisture and fire tests are needed to calibrate a Fire Danger Rating system to UK conditions and fuel types. Investment by the public sector will be needed to create a FDR system that is free at the point of use. Further research is also needed into the composition of smoke from prescribed burning, the distribution and role of black carbon, DOC losses in water related to burning in all habitats and the role of methane.

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