Other:

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Protecting our peatlands

Managing heather moorland to restore, nurture and promote active peatland in the UK's uplands.

A summary of ten years studying moorland management as part of Peatland-ES-UK: heather burning compared to mowing or uncut approaches.

January 2023

UNIVERSITY of York

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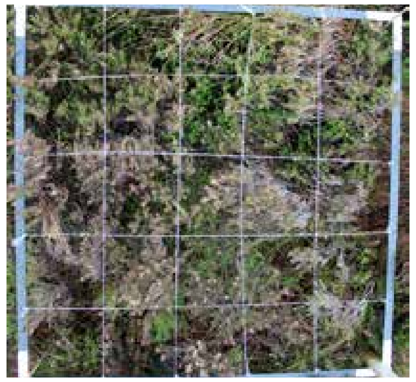


Contents

This document summarises the 10-year report from the ongoing PEATLAND-ES-UK project:

Restoration of heather-dominated blanket bog vegetation for biodiversity, carbon storage, greenhouse gas emissions and water regulation: comparing burning to alternative mowing and uncut management.

We discuss the reasons for the project and the context in which it was conceived, its aims and design, how it was carried out, and the key findings from ten years of work. More details and discussion are available in the full report, accessible at: **https://doi.org/10.15124/yao-2wtg-kb53**

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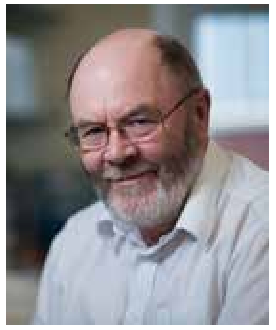
Foreword



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The UK's heather moorlands contain a unique collection of flora and fauna which are recognised as globally important. These beloved landscapes are not only ecosystems, farms and wild game shoots; they also provide drinking water and, especially in the case of peatlands, lock up huge amounts of carbon in the soil, so they are now part of the climate change debate.

Whilst wildfire is a natural and essential part of some ecosystems, we have seen a surge in their number, both in the UK and across the globe. This and the steady increase in the length of the wildfire season has resulted in the UK Climate Change Risk Assessment and National Adaptation Programme identifying wildfire as a climate change risk. Of particular concern is where wildfires burn through the surface vegetation and into the underlying layer of peat. In just a few hours carbon slowly accumulated over thousands of years can be released back into the atmosphere.

Managing biomass and thus fuel loads on peatlands is, therefore, an important aspect to secure a viable future for these ecosystems, which are naturally fire-prone. Whilst there are several management options under consideration to support the resilience of these ecosystems, there is surprisingly little robust evidence on the potential trade-offs for these tools, notably prescribed fire, alternative cutting or no management.

The University of York must be congratulated for having the foresight to design and initiate this long-term study to inform how best to refine heather moorland management - because we can't afford to make mistakes. These are cold and wet ecosystems that respond slowly to changes in management, so short-term studies simply can't provide the information we so desperately need. Evidence provided by long-term studies like this one will also help inform how we best manage wildfire. Peer-review of the Defra report published after the first five years of the project clearly pointed out the need to continue this study over a complete management cycle. After ten years, at the half-way point of this study, the results highlight the value of continuing this vital research in order to obtain policy and practitioner relevant information on management impacts related to vegetation cover, carbon cycling, water balance and biodiversity aspects.

The complexity of scientific report writing can stifle wider public understanding. This is often exacerbated in the uplands because most are unfamiliar with the detail about how our moorlands function. I feel the authors should be commended for producing this Plain English summary of their first ten years of the study. At last, we are beginning to see the answers we have been waiting for as we grapple with how to best manage our stunning heather moorlands - to deliver the outcomes we all seek.

Introduction

Peatlands in the UK

There are many peatlands in the UK, and they are important because peat soils are extremely rich in carbon, storing it effectively for very long periods. In fact, despite covering only 3% of the world's land surface, peatlands contain 30% of all the organic carbon in the soil worldwide. This huge carbon store makes peatlands and their management critical in addressing climate change.

Peatlands are of particular importance in the UK because we hold a large proportion of a rare kind of peat bog. Almost all UK peatlands are the types known as blanket bog or raised bog, and the UK uplands contain around 15% of the blanket bog in the world. Holding so much gives the UK a precious opportunity to preserve and protect these natural carbon stores, so that they can work for us in reducing carbon emissions and combating climate change.

Healthy, active peatlands will absorb carbon, store it and build the peat, but if the balance tips and peatland is damaged or degraded, they can release that carbon back into the atmosphere. Peatlands hold such large stocks of carbon that releases could contribute greatly to carbon emissions. This balance is sensitive, and human decisions such as whether and how to manage vegetation on peatlands are one important factor in a much larger picture affecting carbon absorption or release. Drainage, grazing, pollution, wildfire, and climate change are just some of the others at play.

Blanket bogs and people

In some upland areas of the UK, a layer of blanket bog peat lies draped across the hills like a protective blanket and the landscapes which support this precious feature seem to evoke a deep connection in many that spend time there. Whether it is walkers, conservationists, farmers, gamekeepers, beaters, shooters, hill runners, bird watchers or many others escaping to the outdoors, there is a special quality to such wild and open moorland landscapes which often fuels opinion about how they should be used, managed and protected. However, this image of bleak, ethereal spaces can sometimes mislead and give the impression of an untouched ecosystem where nature takes its course and humans take a step back.

In reality, most UK blanket bogs have been influenced by human management for thousands of years. Originally, forest would have covered many (but not all) of the hills in these environments, and it was clearance by early humans that first opened the landscapes up to reveal what today are often thought of as natural places. Examining peat sections from underground shows that heather and fire have been integral to these uplands for thousands of years. We also know that drainage has been detrimental to peatlands and rewetting is key to restore healthy functions, especially carbon and water storage. Our challenge in modern times is how to approach moorland vegetation management going forwards in view of a changing climate. Do we continue with the methods such as prescribed fire that have become traditional in recent centuries, move to an alternative, yet less well-known vegetation management such as mowing, or take a conscious decision to withdraw management, allow reversion to whatever develops and take the potential risks?

From a practical perspective, not only are our upland peatlands beautiful and valued spaces, but they are also extremely important in many different ways. Peatlands act as a huge reservoir to soak up rainwater, which can slow its flow to local streams and rivers and therefore help to either control or contribute to flooding. It can act as a filter to water passing through on its way to our reservoirs and taps, or it can release more nutrients and particles than we would like into our drinking water. It also holds a huge quantity of carbon which has been locked up from the atmosphere over thousands of years. All of these vital roles can be positive or may be damaging, depending on a multitude of different factors, predominantly the overall health of the peat itself.

Greenhouse gas (methane) monitoring

Moorland management

Techniques for moorland management in the UK have developed and evolved over time, and this can be a very divisive and emotive topic. Around 5-15% of the total UK upland area, and around 30% of our blanket bog, is managed for red grouse shooting, so the topic of moorland management includes and is influenced by heather management for red grouse. Management for grouse shooting includes a combination of heather burning or cutting, predator control and providing medication to help control parasitic worms in the birds. These practices can be controversial, and the association of heather management with red grouse shooting means that such questions are often linked with debates or discussions about moorland management more widely.

Despite this level of interest and the importance of the subject, there is relatively little robust scientific evidence about the impacts of moorland management, particularly vegetation management, on biodiversity and carbon storage. As well as this lack of information overall, the pieces of evidence that are available often conflict each other, which serves to complicate the situation even further. For all the reasons above, moorland management is an extremely complicated area and the different perspectives held by opposing voices in the debate have often fuelled division and disagreement.

Automated weather (climate) station

The challenge for those who manage moorland, and those such as government bodies who regulate this management, is how to develop a sensible, forward-looking, well-informed approach to peatland management in this environment of polarised opinion. The answer can only be: do the scientific research to provide knowledge about the best way to manage these areas, considering all the different roles they play and critical services they provide. We need to allow scientific evidence to form the basis of decision making for moorland policy. This project was designed along with its original funding body Defra, to fill many of those knowledge and evidence gaps.

What is peat?

Peat itself is an accumulation of dead plant material that is only partially decayed or decomposed and has been preserved under wet conditions in this semi broken-down state. It has an extremely high carbon content and is therefore very important because it has the potential to either contribute to or help slow the progress of climate change.

Peat is formed when dead vegetation cannot break down and decompose as normal. It builds up in layers, is compressed and this prevents most of its carbon from being released back into the atmosphere. This is why peat is so good at drawing carbon out of the air – the plants grow and capture carbon, but much is then retained as peat after they die. Peat formation can only happen when the conditions are wet enough. In areas with a high water table, where water levels in the peat are near the surface, the activity of soil microbes which usually break down dead material is slowed. To work efficiently, these microbes need oxygen from the air, and thus they do not thrive in waterlogged conditions. Low temperatures also slow down decomposition, whereas in warmer areas decomposition happens faster, so peat is not formed as readily.

Any vegetation can become peat, but there are particular plants that encourage peat formation even more. For example, Sphagnum moss species are typical peat bog plants which retain lots of water in the cells of their stems and leaves, and also release chemicals that slow down decomposition once they die. These are often called "peat-forming" species and are thought to promote and support peat formation, given the correct wet, cool, slightly acidic conditions.

The Project:
Peatland-ES-UK

Where does Peatland-ES-UK fit in?

Against this backdrop of an emotive topic with polarised groups holding entrenched and opposite views, climate variation complicating things further, the prospect of any research needing to be extremely long term, as well as extremely complex and very varied ecology, it became increasingly clear there were important gaps in our knowledge. Natural England is an independent body which advises the Government, and they reviewed the science about heather burning and moorland management for a report which was published in 2013[1]. During this process, Natural England identified a series of topics where evidence was lacking. Some of these were:

- The effect of heather burning on vegetation and other important roles that peatlands play (related to water quality and flow, carbon, and biodiversity) across more sites in the UK, particularly in the medium to long term (15-25 years).
- Gaseous exchange of peatlands in relation to burning (release and uptake of CO_2 and other greenhouse gases like methane).
- Charcoal/biochar production and its significance to the carbon budget.
- The vegetation response to heather burning and its recovery after a burn.

In these areas, along with others, we needed more research to give clearer answers. For example, previous studies looking at these questions have been mostly short-term and therefore only covered the immediate period after a management technique was used but missed effects further down the line. Others have been limited by their experimental design and the range of aspects and sites they assessed. Another common weakness in studies on blanket bogs is that some research fails to separate the effect of historical moorland drainage from ongoing vegetation management – a complex issue which is nevertheless very important and has a big impact on several features of moorlands such as the quality of water draining from them.

Sunset vegetation survey

Along with the Department for Environment, Food and Rural Affairs (Defra), the Government department that would fund the research they were requesting, Natural England called for scientists across the country to propose research projects that could investigate these questions robustly and provide reliable answers.

Vegetation assessment

Study design

Peatland-ES-UK was designed in response to this request to study heather management. We aimed to look at the impact of rotational heather burning compared to cutting over a typical management cycle of about 20 years on water, carbon storage, greenhouse gases and biodiversity, while also considering other issues such as physical effects on the moorland, practicality and cost. Natural England and Defra chose to support and fund Peatland-ES-UK because it was the only project to have several important characteristics meaning the results would be reliable and robust:

1. It included several sites which cover a range of peatland habitats with different conditions – especially drier to wetter bogs.
2. It was designed with two catchments that are paired at each site - this means that they are similar enough before the study to be comparable. Therefore, differences measured throughout the project can be put down to the management which has been carried out, rather than inherent differences between the study areas.
3. It used a BACI design (see box, p10) - meaning that the effect of the interventions can be detected against any pre-existing variation and using unmanaged areas for comparison.
4. It would be long-term, covering at least the length of time of a whole management cycle. This is the only way to truly understand the effect of management interventions as stopping part-way through gives an incomplete and likely misleading picture.

The project has adhered throughout to these principles, its aims and methods, analyses and interpretation.

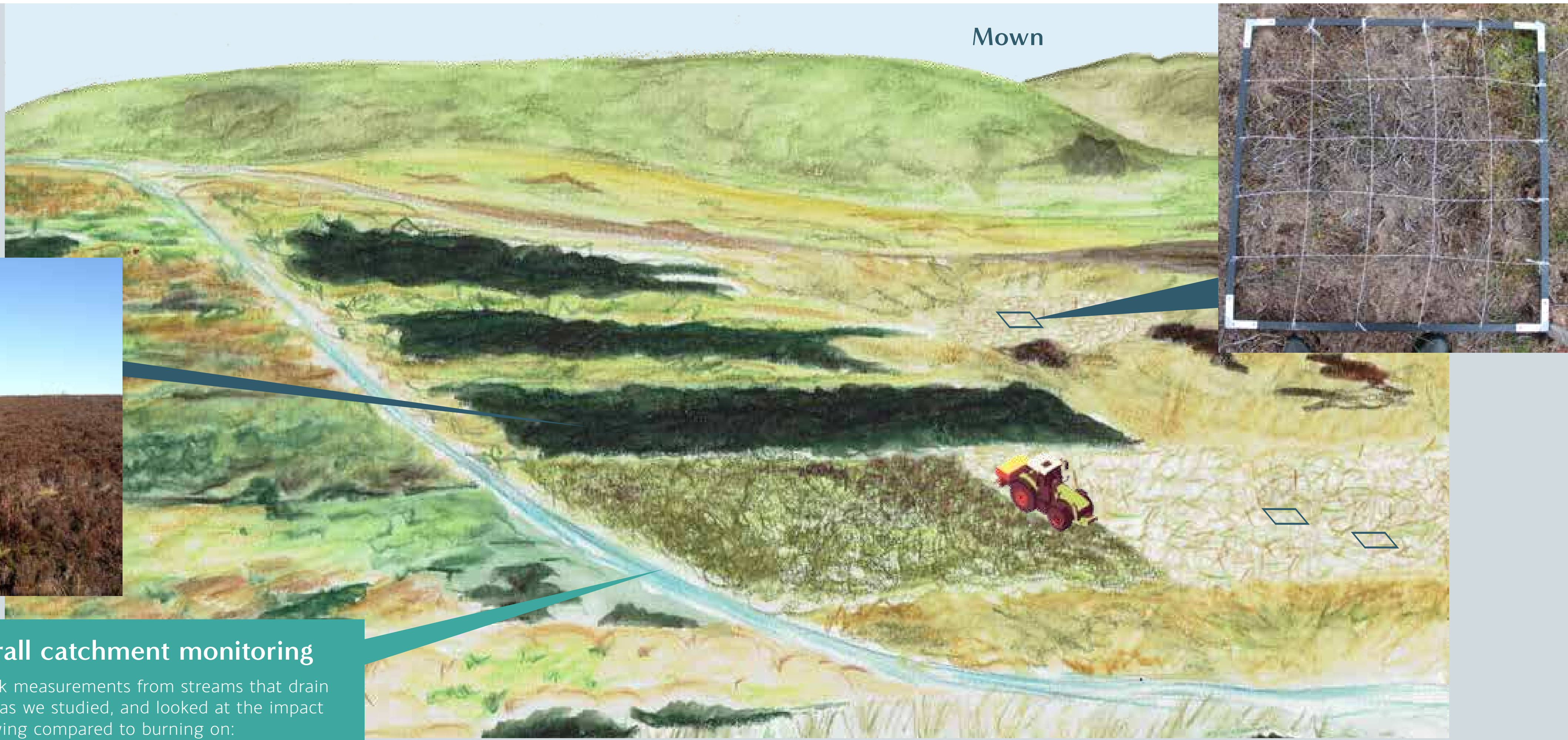
In 2018, another paper was published[2], looking once again at all the research in this field. This identified that many of the research gaps from Natural England's 2013 report still remain, and recommended many of Peatland-ES-UK's aims and experimental approaches. High-quality studies with the attributes that make the results reliable and more widely applicable are still lacking, and Peatland-ES-UK fits the criteria in these areas.

Peatland-ES-UK has three study sites across northern England, with paired catchment areas at all of these that are managed by either cutting or burning small areas in a management cycle about every 20 years. The project design was the same at all three sites, which represent a range of conditions in terms of climate but are similar in their peat depth and plant communities. All three were monitored during the year before management began to establish the baselines and natural differences between the sites, catchments and monitoring plots that are not related to the experiment. This is critical to give reliable results in any study of this sort.

We studied many different things which may have been impacted by our management. By looking at streams which drained the catchment areas, we studied water runoff, peat erosion and stream flow (the amount of water in the streams). By looking at smaller sections of the overall area, replicated monitoring plots which were five metres by five metres, we studied a number of characteristics in greater detail. These were the vegetation response – heather, mosses and sedges such as cotton-grass, the carbon that is stored or released from that area over the course of the study, greenhouse gas emissions, the depth of the water table, water quality, peat pipes (underground tunnels in the peat), and the surface profile of that area – how rough or smooth the ground surface is.

Overall study design

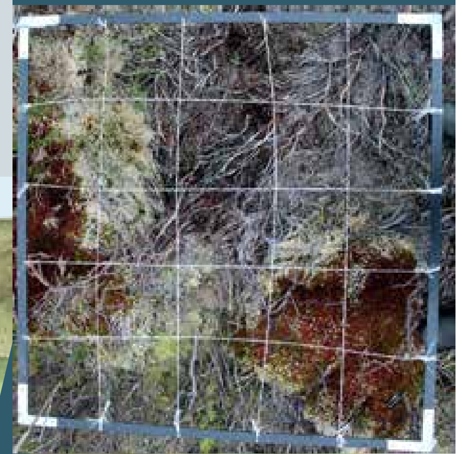
At each site, new patches of about 0.3 hectare of old heather in each catchment were managed over time by either mowing or burning.



Studying plots within the managed areas

We took very detailed measurements from inside 5 m x 5 m plots within the managed and unmanaged areas to understand the impact at a smaller scale. We monitored the vegetation, water and peat properties, cranefly emergence and abundance, the carbon and other greenhouse gases taken up or released by the peat and vegetation in that plot. This helped us to understand the impact of and recovery after heather burning and mowing on:

- Biodiversity, particularly the vegetation response to management
- Carbon storage or release
- Greenhouse gas emissions
- Peat accumulation rates
- Water quality and water table depth



Overall catchment monitoring

We took measurements from streams that drain the areas we studied, and looked at the impact of mowing compared to burning on:

- **Stream flow** – how much water the streams were carrying, which is affected by how much and how quickly it drains from the land
- **Water quality** - how much dissolved organic carbon and nutrients the stream is carrying
- **Peat erosion** – how much particulate matter the stream is carrying

Ground penetrating radar equipment used for detecting peat depth and peat pipes

How to get reliable answers to complex questions: **The BACI study**

One of the main challenges for scientific research is how to design a study which will definitively answer a particular question or set of questions. The time and money spent on any scientific research can be wasted if details are overlooked in the planning stages, so there are certain approaches that ensure the most informative, reliable results. The 'gold standard' for this kind of research includes several important criteria for how the study is structured:

1. The study areas are monitored before you begin, to give a thorough understanding of any differences that exist already, and which might affect the results. This gives the scientists a baseline for the different sites and areas and allows them to account for those differences in the analysis later on. Without this site monitoring beforehand, the results are very difficult to interpret and rely on.
2. Once you have this foundation of knowledge, the interventions are implemented in a specific and controlled way, where possible changing only one variable in each situation and monitoring all the outcomes that might be impacted.
3. One study area is included where nothing is changed. This can be used as a reference area to tell us what would have happened naturally, for example due to climatic impacts, if we had not intervened and is a critical component of any experiment. This area is called the control, and results without a control for comparison hold little power.
4. Monitoring is comprehensive, replicated, regular, according to suitable protocols, and is continued afterwards for an appropriate amount of time to understand and test for the full impact of your intervention, thus answering the original questions.

Studies which adhere to these criteria are known as **BACI** studies, which stands for **Before-After Control-Impact**. This is considered to be the most powerful way to give reliable results when studying human impact in complex systems such as the effect of heather moorland management

The importance of site – why does "where" matter?

Blanket bog site with heather and cotton-grass.

The sites you choose when planning any study are all-important. Well-chosen sites lead to robust, clear results but studies with single or inappropriate sites can give difficult to analyse or even misleading information.

Paired study areas are key, ideally with several sites that cover a range of conditions. The areas are matched for as many characteristics as possible, such as height above sea level, rainfall, vegetation, steepness and any management etc., to minimise the effect of pre-existing differences between the sites. Monitoring the sites before you begin your experiment or make any management changes is also vital. Only with this approach can you be sure that the results you later find are genuinely down to the management you are testing, and not unrelated factors. This is a critical point for the reliability of the results you find.

Studies without these qualities can produce results that are much more difficult to interpret, with more uncertainty and limitations. The moorland ecosystem is very varied, and it can be challenging to find suitable sites to compare to each other and give reliable answers. This means that often, studies into moorland management have been carried out without the appropriate design – adding to the confusion within this area of science. Different studies give seemingly conflicting results, and there is not yet any consensus amongst the scientific community as to the best way forward for moorland management[3].

One good example of this is that few studies adequately consider differences in drainage between their study areas, and yet drainage has an enormous impact on almost all characteristics and functions of a peatland. Water table height, water quality, how water flows across and through the landscape, the ecosystem health or 'active' status of a peatland, its greenhouse gas emissions, and the vegetation present are just some of the aspects affected by peatland drainage. To attempt to compare sites with very different conditions like drainage situations and attribute any findings instead to the current management approach very likely renders the results meaningless. Unfortunately, this leads not only to wasted time and money, but also to more confusion around the effects of different management in an already volatile debate.

To resolve this disagreement, we need more studies like Peatland-ES-UK which are long-term, with replicated sites on comparable areas and based on a robust BACI monitoring design to produce reliable results.

Why crane flies?

The crane fly, or daddy-long-legs may seem an oddly specific choice to focus on when studying moorland biodiversity. However, it provides an easy-to-measure way of looking at the impact of management on insect biodiversity in the area. Crane fly larvae spend the summer and winter below ground, then emerge in spring. This means we can assess the effect of management techniques on the number emerging. For example, mowing or burning can affect water tables, and cranefly are sensitive to soil moisture, so they may be impacted. Insects which move around are harder to use as a measure of the effect of intervention at a certain spot. Crane flies can also be a useful general indicator of biodiversity in the area. They are an important insect group on moorlands because they represent one of the major protein food sources for moorland bird chicks, so their abundance can give an indication of how biodiversity may be faring in the ecosystem more widely.

Tractor used for mowing heather at one of the peatland sites in 2015.
The foreground shows mown areas from the initial management in 2013.

Results

Key findings of Peatland-ES-UK

Peatland-ES-UK is a large, ongoing study which has so far produced a huge amount of data across many areas. The preliminary results suggest very important findings. However, these have to be considered intermediate because the study is ongoing. Here we report the key findings so far in certain areas, with some predictions for the future, but (funding permitting) we will continue our work to understand the response of our sites to management throughout at least a whole management cycle of around 20 years.

Vegetation

Overall, the diversity of plant species we found on all the sites was fairly low (highest on the wettest site and lowest on the driest site). One of the aims of this study was to look at ways to reduce heather dominance when heather cover is very high as this is thought to be to the detriment of other species. Both burning and mowing led to lower heather cover, as it removed the above ground vegetation. Cotton-grass and Sphagnum mosses both increased after either management approach.

So far both burning and mowing appear to support 'active' bog vegetation. They opened up the heather cover to allow Sphagnum and other mosses to increase, along with other shrubs, herbs and sedges. One site showed a much higher Sphagnum increase after either management compared to the uncut plots. The burnt plots had the highest species richness and diversity from around two years after management.

Dense heather canopy of old plants (about 35 years) at one of the peatland sites.

In the first few years after management, bare and burnt ground was highest on the burnt plots and brash cover was highest on the mown plots. This was expected, given the management that had been carried out. Both effects were temporary, and after four years the managed plots were similar again.

Heather regrew after both burning and mowing, initially slightly faster on mown plots but again after 4 years the two treatments were the same for both heather height and cover. Heather beetle attacks after that point had a severe impact, with the worst effects being on the burnt plots at wetter sites and mown plots on the driest site.

The uncut 'do nothing' option showed some downsides, especially overall lowest plant diversity as well as the limited recovery of a supportive 'peat-forming' layer of mosses at the driest site. The greatest increase of non-Sphagnum mosses was seen on uncut plots, and Sphagnum moss cover remained high (not increasing much after 2013), but the overall diversity of vegetation species was low. Heather cover stayed high throughout the project.

In terms of vegetation height and structure, we saw two effects that could impact moorland birds. Both burning and mowing reduce vegetation height compared to uncut heather, which is important for some ground nesting birds. Tall heather severely limits ground nesting sites for those birds which prefer a more open situation such as Golden Plover. Burning reduces vegetation height more and for longer than mowing. Cutting heather with machinery also removed the tops of grassy tussocks and moss hummocks on the moorland. This means that the ground profile is smoother, with lower clumps of e.g. cotton grasses. Some moorland breeding birds use these higher areas as dry nesting sites away from the wetness of the peat surface, so this levelling out of the surface profile that results from cutting to a uniform height may impact some bird species. (See illustration on p17).

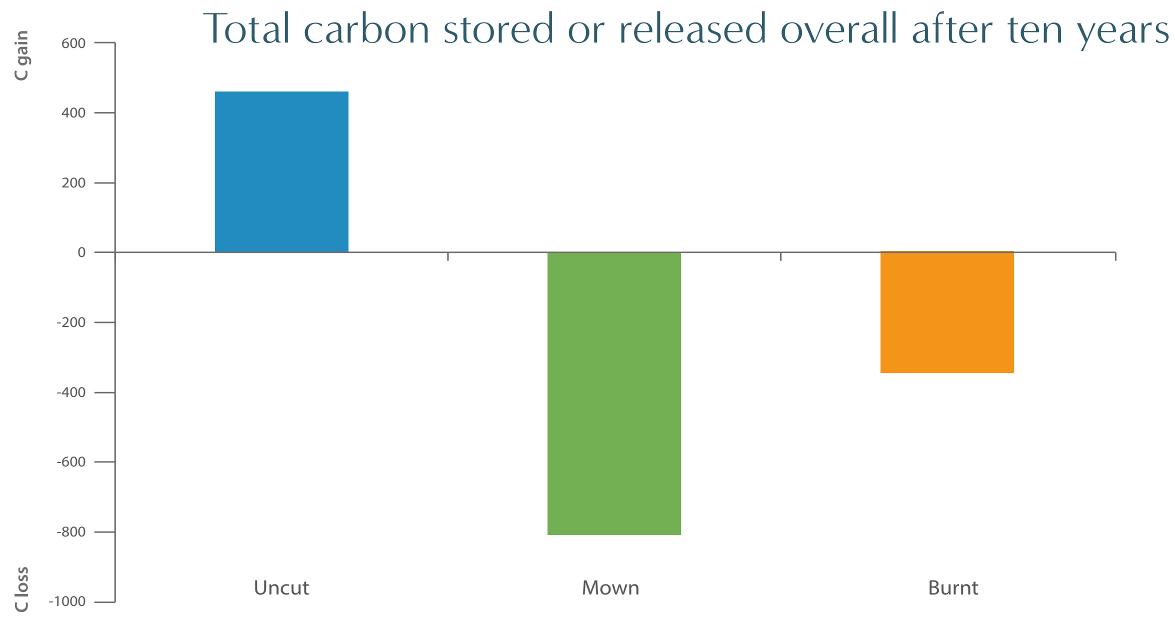
We also measured the nutrient content of heather shoots, which is thought of as being important for both sheep grazing and red grouse diet, but it is also important for carbon uptake. The nutrients we studied include nitrogen, phosphorous, potassium, magnesium and manganese and these elements are involved in photosynthesis. Faster growth and more carbon uptake is possible when the necessary nutrients are available to the plant, as well as being more nutritious to animals that may eat it. We found the nutrient content of heather shoots was improved after either mowing or burning but was improved more and for longer after burning for some elements relevant to carbon uptake, probably because of fertilisation provided by the ash. It is likely this allowed faster growth, which contributed to a faster recovery towards carbon uptake on burnt compared to mown plots.

Heather Beetle
small but devastating

Starting in the summer of 2016, some of our study areas suffered frequent and severe heather beetle attacks, predominantly at two sites and first on burnt then later also on mown areas. These seriously damaged heather vegetation, with a devastating impact on the ecology of the moorland. The damage led to high carbon releases continuing over subsequent years. Although heather beetle outbreaks are a fairly common event on moorland in the UK, those that happened on the study sites (different sites and areas at different times) were much more severe and widespread than is usually seen, with noticeable effects on the carbon uptake and release we measured between 2017 and 2021.

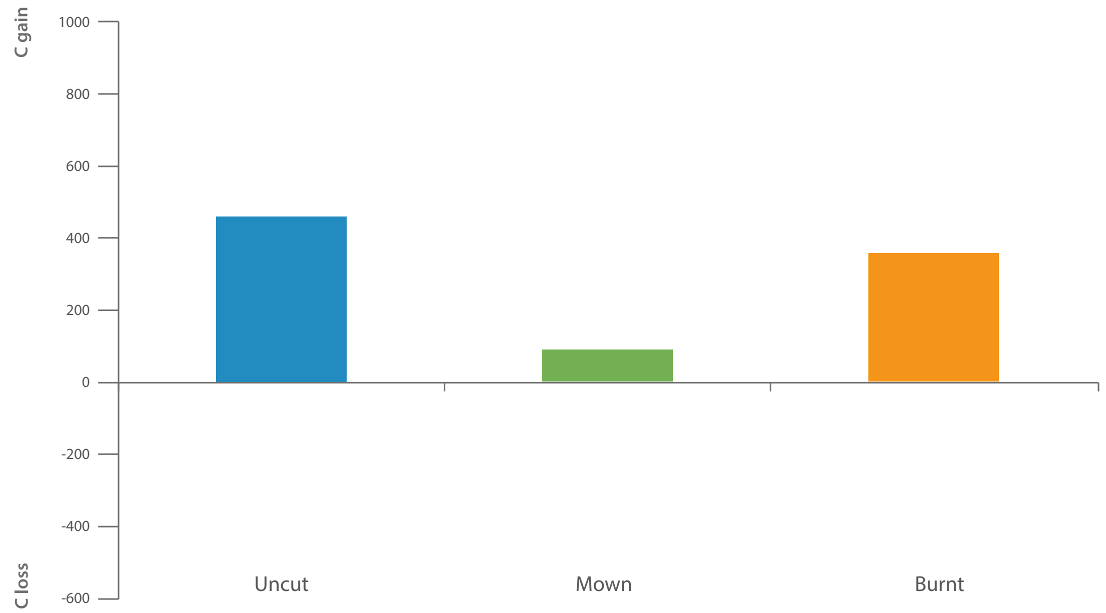
This event was unrelated to the management we were studying and severely affected the results. To understand how serious the impact was, and estimate what would have happened without such severe heather beetle problems, we used data from the unaffected areas and time periods to inform what the long-term carbon uptake may otherwise have been. This allowed us to estimate predicted scenarios – these represent what we think we would have seen, if heather beetle outbreaks had not impacted the study. Therefore, some results are measured data, and some are predicted estimates.

The impact on carbon storage in this study was very large. Both burnt and mown areas were affected at different times, but unmanaged plots were not, as is often observed. The actual measured cumulative data showed that areas managed with either burning or mowing released more carbon in total than they absorbed over the ten years of the study, including the releases caused by heather beetle. Mown plots released the most carbon, burnt plots released less and uncut plots (which were not affected by heather beetle) took up carbon overall over the ten years of the study so far.



This graph shows the total ten-year carbon balance to date for the three management approaches, expressed in grams of carbon taken up or lost overall per square metre of peat. This figure includes estimated burn emissions from combustion, charcoal gains and the carbon lost as a result of heather beetle damage.

However, when we calculate and predict what we think would likely have been the case if heather beetle outbreaks had not affected the carbon balance, the results look very different. The predicted total cumulative ten-year carbon balance to date for the three management approaches are shown in the following graph. These estimated values exclude heather beetle damage but include estimated burn emissions from combustion, and charcoal gains.



This shows that all three management approaches are predicted to take up carbon overall. Ten years into the study, we would expect the uncut plots to have absorbed the most carbon, burnt plots slightly less, and mown plots the least.

This is another example of why it is important to carry out long-term projects, to gather a big enough picture that unusual events such as these do not skew the overall results. If a project only continues for five years and three of those are affected by heather beetle or other chance events, you cannot draw meaningful conclusions about what may happen under normal circumstances.

Prescribed fire at one of the peatland sites during winter 2018.

Carbon uptake and emissions

The overall figure for carbon uptake and release from peatland reflects carbon travelling both in and out of the system through many routes, which for this study included:

- Carbon released during burning
- Carbon released from decomposing brash left on the surface after cutting
- Carbon that was taken up from the air when vegetation grew
- Carbon that was released from the peat itself, for example if the water table dropped and the peat began to decompose
- Carbon that was lost in the water draining from the area

Taken together, these inputs and outputs combine to give an area its overall **carbon balance**. We used gas chambers to measure CO_2 and methane going in and out of areas of peatland, as well as carbon that left the catchments in local streams. The carbon in streams was affected by many other factors and areas as well as what was going on in the study plots themselves, so although we took and compared those measurements, we could not confidently include it when working out the overall impact on the carbon balance of particular areas.

How carbon flows through all these routes varies enormously over time following any management technique, or as an unmanaged piece of peatland ages. We and many other research groups have studied the first few years following treatment up to around 5 years. PEATLAND-ES-UK now also has data for the 5-10 year window, but very few studies have continued their monitoring out to 20+ years. The intermediate results we report here suggest that the picture changes dramatically from 0-5 years compared to 5-10 years. We can predict, but do not know, what will happen in the second half of the management cycle unless the project continues over at least the next ten years.

Carbon flux monitoring over recently managed ground

Unmanaged plots

Unmanaged heather areas took up carbon overall throughout the study, indicating an active bog status and growing vegetation especially on wetter sites. However, as the project progressed these areas took up less and less carbon over time. They remained a carbon "sink" – taking up rather than releasing carbon each year over the 10-year period, but as the study continued and the heather aged its growth slowed, the water table dropped, and the peat became drier with higher decomposition. All these things limit carbon uptake.

At this ten-year point, the unmanaged areas are predicted to still be a carbon sink but are taking up less than half the carbon per year than at the start of the study – still slightly more than the cut areas, but less than half the absorption of the burnt areas each year.

Burnt plots

There was a large release of carbon during management as the top layer of vegetation was burnt, as well as the associated air pollution such as from particles. However, the peat itself was not damaged so the carbon stored there was not released. Carbon loss from the burnt areas was more than from the mown areas for the first two years, but then carbon losses fell as vegetation regrew. By 2015, two years after burning, burnt areas were taking up more CO_2 per year than they were losing and were therefore a carbon sink, although it was not yet enough to make up for what had been lost as emissions during the burn.

One of the analyses we did gave a progressive yearly average carbon balance, which included both the estimated carbon lost in combustion during the burning (divided over the whole burning cycle) as well as carbon stored in charcoal and charred sticks afterwards. These suggest that without heather beetle damage (discussed in box on p14) the burnt area would be taking up carbon as a carbon sink by around 5-7 years after treatment, even considering carbon losses from combustion. By around 8 years after burning, this management would be taking up the most carbon per year of the three management options. At the ten-year point we have now reached, the predicted carbon balance for the burnt plots shows it can absorb more than twice the carbon per year compared to either the mown or unmanaged areas, which are very similar. Our prediction is that this will continue to rise slightly for the next few years, then stabilise at a similar level of carbon uptake to what it presently absorbs.

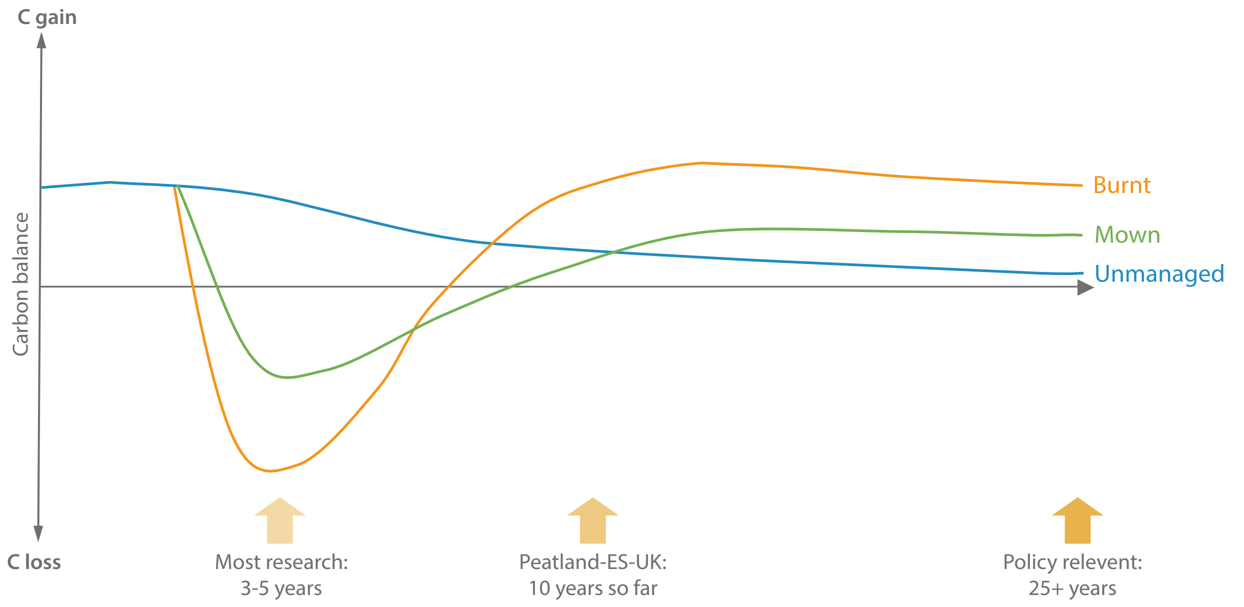
The role of charcoal, other charred remains and ash in carbon capture is potentially very important. The carbon stored in charcoal is very stable and will not easily break down, so can contribute a great deal to the carbon capture potential of the area (discussed on p18).

Mown plots

There is no initial large carbon release during mowing as there is during burning. Instead of being burnt off, the cut vegetation is left at the site (as it is impractical to remove brash from large areas and removal would deprive the site of key nutrients). Although the initial large carbon release from burning is avoided, this brash on the surface then gradually breaks down and decomposes and most of the carbon that was contained in the plants is released over time back into the atmosphere. This leads to mown areas becoming carbon sources in the first years after management, releasing smaller amounts of carbon after management than burnt areas but for much longer. The amount of carbon that is released per year, when including the burn emissions and excluding heather beetle impacts, is predicted to be lower for mown than burnt areas for the first 7 years, but the transition from carbon emission to carbon uptake is more gradual for mown sites and it takes longer for them to become carbon sinks compared to those that were burnt.

Mown sites are predicted to switch from overall carbon release to overall uptake per year around 7-9 years after treatment, and then absorb carbon as the vegetation is growing and forming peat. Mown sites likely overtake unmanaged areas at about ten years after management in terms of how much carbon per year they can take up (at that point the unmanaged areas had a heather age of approximately 35 years). They then level out, absorbing approximately twice the carbon of unmanaged sites, but around half the carbon uptake of burnt areas.

Mowing makes the ground profile flatter and less bumpy as it takes the tops off the vegetation tussocks. This may have effects on bird nesting sites as well as water flow across the surface.



Carbon Balance Scenarios

This graph sums up the carbon story for the three management scenarios, excluding heather beetle damage. It shows the "progressive average" carbon balance for each year. This means that the total carbon released or absorbed in the area up to that point in the project was averaged over the number of years that had elapsed by then. It includes estimated carbon losses during combustion or brash decomposition, as well as carbon that is potentially stored as charcoal. This graph shows how much carbon may be lost or gained per year under the three management approaches.

Predictions are made to around 25 years, and as the project progresses we aim to replace these estimates with measurements. To understand the full picture over a whole management cycle, and therefore be able to have usable information to develop effective moorland management policies, we need at least ten more years of data.

The impact of charcoal

When heather is burnt most of the carbon is lost to the atmosphere in smoke, some is converted to ash and charcoal and yet more to partially charred sticks. All these different fates for the carbon that had formed the plant are important. In the past, very few if any studies have considered the carbon that remains as charcoal or charred remnants.

During a burn, we found that up to 10% of the vegetation and litter biomass was likely converted into charcoal or charred remains. Another 15% likely became other, similarly stable forms such as semi-burnt sticks that will also not decompose as readily as the original plant material. This is similar to the sort of results other researchers in the area have found[4], and is also confirmed by our peat core work in this study, which showed that over the past 300 years where there was charcoal, there was higher carbon accumulation rates. In terms of capturing and securing carbon into the ground long-term, rather than allowing it to decompose and be released back into the atmosphere, charcoal may play an important role. Charcoal is highly stable and resistant to decomposition, but its presence in the soil also seems to both suppress decomposition of the peat around it and reduce methane emissions from the burnt areas by stimulating conversion of methane to CO_2. Methane is a potent greenhouse gas that climate change researchers are beginning to understand better (this is discussed on p20).

Burnt Catchment

For comparison, on a mown catchment, brash left on the surface will decompose and release more of its carbon to the atmosphere, much like a garden compost heap. After mowing, due to decomposition less than 5% of the vegetation mass is likely to be converted into peat for long-term carbon storage.

Water tables

The level of the water table on peatlands is important because peat is formed best under cool, waterlogged conditions. When the water table is high and the peat is wetter, air and oxygen cannot get to the dead vegetation, microbes in the soil cannot break it down fast enough, so most of the carbon is protected. When air gets to the peat, oxygen becoming available increases decomposition, and the stored carbon is released quickly.

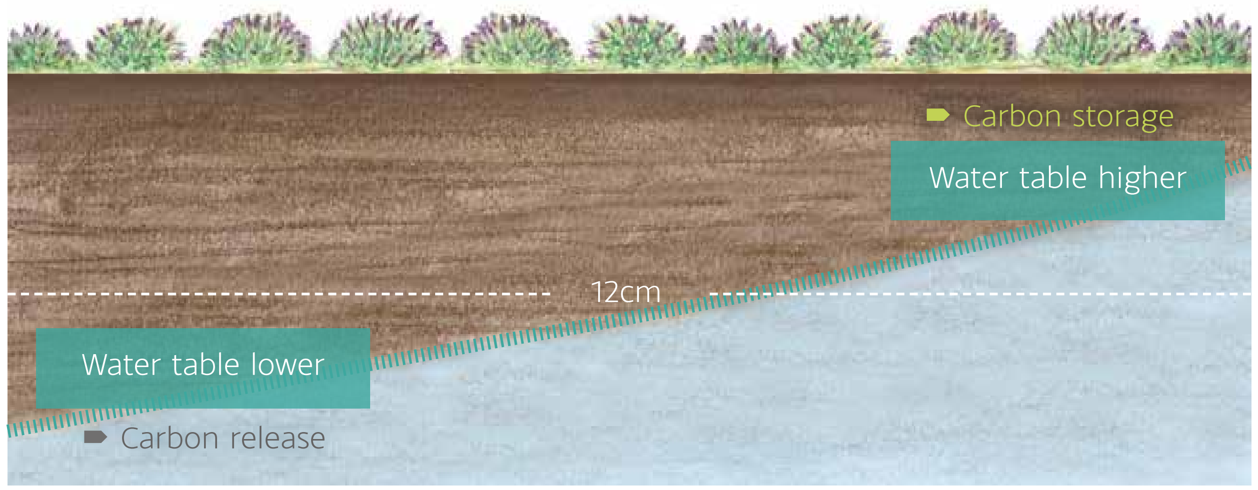
The water tables in our three management areas responded differently. In areas of unmanaged heather, water tables gradually dropped over the course of this study as the peat dried out and had the lowest water table by the end. This is probably because as the heather gets older and larger, there is more plant matter above ground. The roots supply water to this larger plant by transporting it up from the peat to the leaves, which use it to fix carbon as they photosynthesise. Most of this water is lost to the air from pores in the leaves in a process called evapotranspiration.

Mown areas were the wettest in the first few years, with water tables rising around 2 cm after management, but these then gradually dropped over time. The water table in burnt areas was in between the two others in the first few years after management but became wetter in the second part of this project. Towards the end of our monitoring, seven to nine years after management, the uncut areas are the driest with water tables around 13 cm below the peat surface, whereas both the mown and burnt areas have water tables around 11 cm underground. However, compared to the mown areas, burnt areas had become wetter over time, as they had been lower in the monitoring period of the project before management began.

This water level is interesting because our results suggested a threshold at about 12 cm below the surface which determines whether a peat bog is likely to be a carbon sink, or a carbon source. Areas which are wetter, with the water table less than 12 cm below the surface, are more likely to absorb and store carbon, but areas that are drier, with a water table deeper than 12 cm, are more likely to release carbon. Our study supports other research which has also found this 12 cm threshold[5,6].

The main factors that affect water table depth are the characteristics of the area itself such as rainfall, drainage, slope, peat depth, temperature and so on. Heather management strategies can affect water table to a certain extent, especially in relation to no management, but the particular situation of a site is the most important thing.

Impact of the water table: carbon release versus storage



Methane

Methane is a potent greenhouse gas that contributes significantly to climate change. Over a 20-year period, it has more than eighty times the warming effect of CO_2. It is thought that about a third of all human-driven warming since pre-industrial times is due to methane emissions, mostly from energy and agriculture[7].

On peatlands, some types of bacteria which live in the peat release methane, and other soil-dwelling bacteria use it as a food source by breaking it down – so the balance between how much is produced and how much is used is important for overall emissions. Both of these factors are affected by the local conditions including temperature, water table depth and vegetation.

There were clear differences between methane release from peat under the three management approaches in our study. From all the sites, there was a peak during 2015-2017 when the weather was warmer and wetter, and the peat became less acidic. Although the temperature rise was relatively small, in conjunction with these years being wetter the conditions seemed to tip into much higher levels of methane release across all the sites. This is very important for moorland management and climate change, given that such small changes made such a big difference. This data suggests that upland peat bogs in the UK seem very close to a threshold temperature which may lead to much higher methane release under wet conditions.

Experimental burn in winter 2013 showing white ash, black charcoal and patches of intact moss after burning. The shovel is used to restrict the spread of fire at the sides.

From 2018 onwards, methane levels fell again across the sites. During the high emissions period, areas where the heather was not cut or burnt released much more methane than areas managed by either technique. Mown plots released an intermediate amount of methane, and burnt areas released the least.

Uncut areas released by far the highest levels of methane, and we are investigating the possible reasons for that. Uncut areas were overall the driest areas, but drier peat bogs are usually associated with more CO_2 emissions and less methane. On our areas of unmanaged heather, methane emissions were higher than all other areas, even than those that had higher water tables.

The differences between mown and burnt areas are thought to be partly because of the amount of sedge cover on the different treatment areas, and partly because of the charcoal produced. The hollow structure of sedge leaves can act as a chimney, allowing methane produced by microbes deep in the peat to pass through the roots, stems and out through the leaves into the air. Mown areas had more cover of sedges such as cotton-grass than burnt areas, which is likely to have allowed more methane release from the soil on these sites.

Charcoal left from burning also seems to suppress methane emissions, as charcoal in the soil helps speed up the conversion of methane to CO_2 before it is released. These two points together help explain why mown areas emitted more methane than burnt areas.

River flow near one of the peatland sites showing the brown colour of peatland water indicating high content of dissolved organic carbon.

Water quality and flow

Overall, the differences we measured between burnt and mown catchments in terms of water flow and quality were relatively minor. They suggested that overall, the volume of water flowing out of the mown catchment after management was 9% less than in the burnt catchment.

This might be because the journey taken by rainfall over the peat surface and into the stream was slowed by brash that was left after mowing, compared to burnt catchments. At the driest site, there was more of a difference with a significantly higher stream peak flow (the highest flow rate the stream reached after rainfall) as well as a shorter time to reach this peak following rainfall in the burnt versus the mown catchment. Water travelled more slowly across the mown catchment at the driest site, the stream rose more slowly and reached a lower peak than at the burnt site. This may also be because, in these second five years of the project, the water table on older burnt areas of this driest site was higher than mown areas, meaning that the peat was already more saturated, and there was less capacity for water to be absorbed.

Measuring peatland water flow

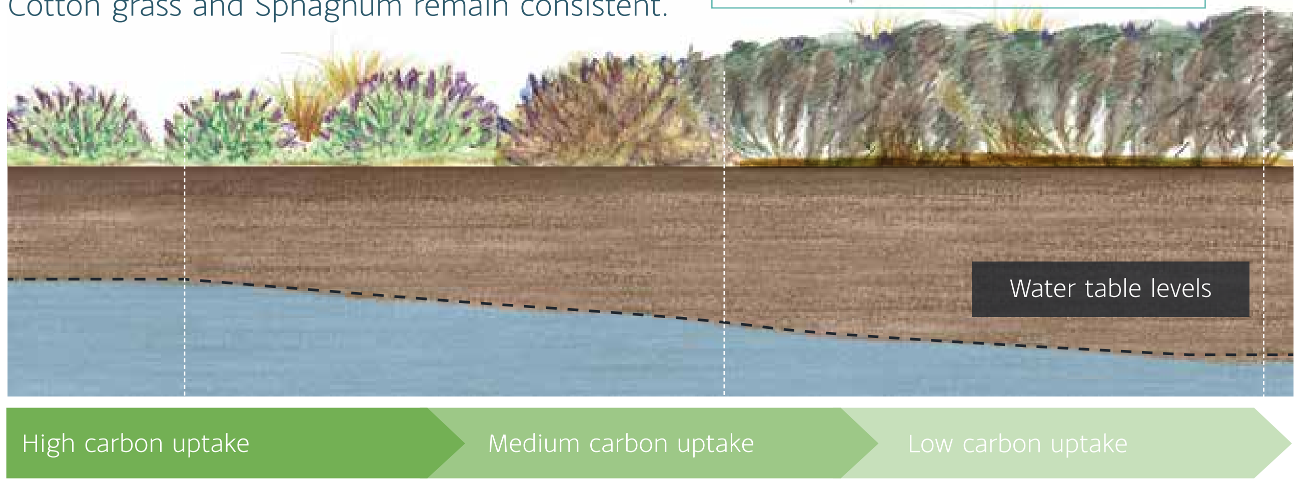
We saw only a slight difference at two sites, when water tables were equally near the surface for both treatments. Overall, the rate of rainfall runoff or retention in these almost saturated catchments was similar and the two areas behaved the same.

Although there were small differences in stream flow between the streams fed by areas under different management approaches, the main factor that affected both water quality and flow was pre-existing site characteristics. These include vegetation, rainfall, temperature, climate, and drainage amongst many other things. The impact of different management techniques was minor in comparison.

Overall Findings

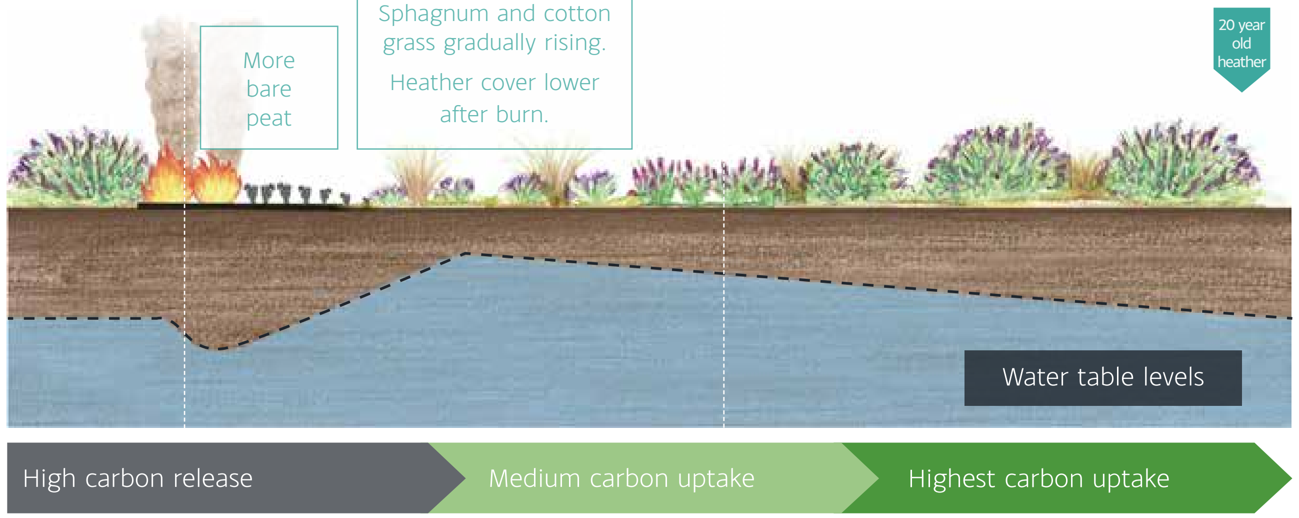
Unmanaged

Highest heather cover throughout.
Cotton grass and Sphagnum remain consistent.



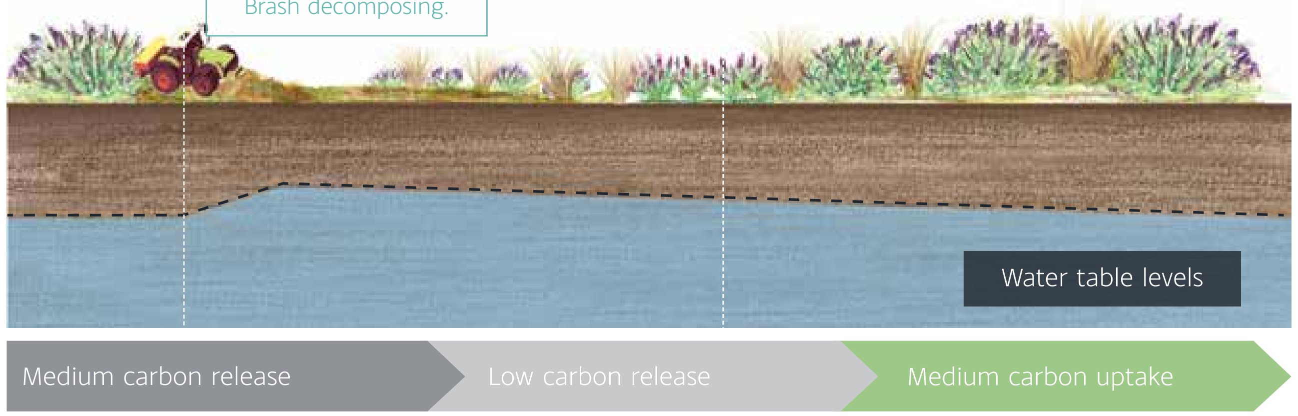
Burnt

Fuel load lowered



Mown

Fuel load lowered



Years of project 0 10 20

Wildfire

Wildfire is an increasing threat in the UK uplands as climate change leads to warmer summers and more droughts[8]. Wildfires have been seen more and more on UK moorlands in recent years, and they can be catastrophic if the fire burns down into the peat itself. They can be almost impossible to extinguish, smouldering in the peat and reappearing for many weeks or even months at a time. Wildfires in these environments can lead to enormous carbon releases, devastating the ecosystems and impacting everything that depends on them. Whilst controlled heather fires are small, about 0.3 hectares, and are done mostly during cold and wet conditions, wildfires can be vast and likely happen during warm and dry periods. Recent wildfires on peatlands include the Saddleworth and Flow Country fires, of around 3500 - 6000 hectares.

Managing the risk of wildfire is therefore an increasingly important consideration when it comes to making decisions about moorland management, but it is an area which has very little scientific evidence in the UK. As a country with a relatively cool climate and low fire risk, peatland wildfire has attracted little research attention. Several more wildfire-prone countries in the world have a much greater base of scientific evidence on wildfire management, and we are wise to learn from them in the absence of information that is UK-derived, until we have more evidence to guide us from our own uplands.

Therefore, out of necessity, wildfire considerations in the UK currently should be based on sensible, practical observations and plausible arguments of what we know from elsewhere, rather than wait for firm UK evidence. For example, wildfires are more likely when there is a high fuel load, and very wet areas are less likely to burn than drier ones. However, even wet areas can dry out during summer and where there is a build-up of dry vegetation and/or thick brash or litter layers. On dry ground, fire can take hold more easily and burn hotter.

The evidence from this study shows that leaving heather unmanaged increases the fuel load over time, as well as the water table gradually dropping and the peat becoming dryer. This is supported by other studies of long-term unmanaged heather, even on one of the wetter moorland sites in the UK[6]. Our data show that managing heather by mowing leads to a slightly higher water table, making the peat slightly wetter in the short term, but this effect gradually ebbs away, and the peat becomes drier over time. Sites which were managed with burning were initially slightly drier but became wetter in the longer term.

Although water tables and peat wetness are important, and the difference is noticeable especially in the winter, if there is a spring or summer drought this slight difference in water table will not prevent the peat surface becoming dry, nor will it prevent wildfire. Furthermore, management by mowing does reduce the fuel load in the growing heather itself, but brash which was cut and left from winter mowing later dries out and can provide ideal tinder for ignition and smouldering in subsequent summers.

Overall, our assessment of wildfire risk on heather moorlands is that if you do not manage these systems they will eventually burn, very likely during warmer and drier periods, with potentially catastrophic carbon losses. Management with prescribed burning or mowing reduces fuel load, but with the initial carbon cost of loss through controlled combustion or longer term from decomposing brash. We are beginning to study this as part of a large collaborative programme of research (IDEAL UK FIRE) funded by the Natural Environment Research Council.

Conclusions

These results are the findings from the first half of a long-term study. Although Peatland-ES-UK has already continued for longer than nearly all other moorland research, it is important that the work covers at least the length of a complete management cycle. To produce results that are robust and long-term enough to guide moorland management policy, we plan to continue the project for another decade. This was the conclusion when our Defra project report[9] was reviewed by external scientists after five years, and it remains the case. However, the results to date suggest some very interesting and important findings, which may begin to help any interested parties who are confused by the seeming contradictions in the science previously.

All three management approaches were able to support active, healthy peatlands in which peat can grow and carbon can be stored. This is also the finding from some other long-term studies[6]. Both burning and mowing release considerable amounts of carbon during or in the first years after management, but this is counteracted by increased absorption later on. Short-term assessments are therefore misleading. Heather management also seems to increase biodiversity and maintain higher water tables in the longer term, compared to areas of unmanaged heather. Where a site is wet enough to use prescribed burning, this seems the most suitable option to allow carbon storage, peat growth, reduce heather dominance, increase biodiversity and keep the peatland wet. Where a site is drier, mowing could be more appropriate and may help keep the site wetter in the short-term. This threshold sits at a water table of around 12 cm below the peat surface.

Do we need to manage heather on moorlands at all?
The results of our study found that unmanaged areas of heather had several drawbacks, including the water table dropping and peat drying out, the associated carbon loss from decomposition, but also higher methane emissions. Ageing heather gets less and less efficient at taking up carbon as its growth slows, but as it remains dominant, we also saw lower biodiversity at unmanaged sites. Unmanaged areas continued to take up and store carbon and were overall the highest carbon sink of the three approaches so far, but the slowing carbon uptake and increased emissions we saw suggest that in the long term peatlands will lose health and activity under this approach. Wildfire risk is also very likely highest on unmanaged areas and could have devastating impacts on all aspects.

So far, Peatland-ES-UK finds that different management approaches have different benefits, depending on the site and circumstances. Prescribed heather burning, mowing or leaving areas unmanaged should all be available to practitioners so they can choose the most suitable technique for their site.

Walking up to one of the monitoring sites.

Are the results from one study that important?

Given the increasing number of studies in this area, and the difficulty that can come with interpreting them, it can be tempting to be influenced by the number of pieces of research that seem to point to one or another outcome. This straightforward tallying up approach can give a reassuring feeling in the midst of a confusing situation that the "weight of evidence" suggests a particular answer, in this case that heather burning is damaging, but there is a potentially dangerous drawback. If each piece of evidence is equal and it is merely a case of accumulating enough to consider the case closed, it can be appropriate, however, this numerical approach does not work in more complex situations.

Unfortunately, some research in this area has serious methodological limitation and flaws like the ones we described above. Not carrying on for long enough, not having appropriately matched sites to know that the conclusions drawn genuinely reflect management rather than site differences, a variety of drainage situations, or other factors, mean that these pieces of evidence are not all equal. That is why Defra and Natural England identified important gaps in our knowledge in the first place, and Peatland-ES-UK was designed to address those with an approach that would be robust enough to confidently fill them. Moreover, this is the only such study to address all major aspects in a holistic way, capturing impacts on carbon, water and biodiversity. Both the intermediate results reported here, and the final results we expect to generate over the next ten years will be crucial to help clarify some of the disagreements around moorland management.

Project funding

This project was designed in response to a Natural England and Defra request. The aims, methods, sites, design, etc. were approved and funded for the first 5 years by Defra. A Project Advisory Group was established with representatives from a wide variety of interested parties including water companies, conservation groups and shooting organisations. This group as a whole was consulted and updated throughout the project and helped to act as an external source of advice and input.

After the first five-year phase of the project, Defra funding was not continued. The Project Advisory Group recognised the value of the work overall, the value of what had already been carried out and the importance of continuing into the medium and long term, according to Defra's and Natural England's original intention. The organisations represented on the Project Advisory Group as a whole worked collaboratively to provide funds with which to continue the research. Funding for the second five years of the project therefore came from organisations with a range of backgrounds and beliefs, united by a common recognition that the only way to a positive and productive plan for future moorland management is to answer the questions that had been identified, in a way that gives reliable answers, over a timescale that is appropriate.

The project itself remains the same and was not influenced in any way by this change in funding stream. In recent years some voices in the scientific community have used this as an excuse to call into question the validity and credibility of the research and of those who carry it out. To do so ignores the important facts laid out above that the project, its analyses and interpretation have continued exactly as planned at the onset by ourselves and Defra and the findings retain that value and credibility; a fact which has also been recognised by further funding from the Natural Environment Research Council.

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For more information, please read the full ten-year report, available at: https://doi.org/10.15124/yao-2wtg-kb53

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