Calderdale Blanket Bog Condition Assessment and Wildfire Severity Assessment Report

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Executive Summary

This report is intended as a contribution to the debate about wildfire prevention and mitigation. Moors for the Future Partnership (MFFP) were commissioned by Calderdale Natural Flood Management Group, and funded by the Environment Agency, to assess blanket bog condition and wildfire severity risk in the Calderdale metropolitan district area.

This study achieved the following objectives:

- To identify the state of blanket bog on areas of deep peat within the Calderdale area based upon the Upland Management Group's Six States of Blanket Bog.
- To identify areas of high wildfire severity risk on deep peat within the Calderdale area.
- To set out the current context of blanket bogs within Calderdale Council's area in terms of carbon, biodiversity, policy and water resources including flood risk and water quality.
- To map the location of known water resources and access routes within the survey area.
- To provide an overarching view of the potential management interventions and other wildfire mitigation measures that could be undertaken in these areas.

"Wildfire severity" is defined as the loss of, or change in, organic matter above ground and below ground, including secondary impacts such as subsequent soil erosion. A high severity wildfire, therefore, will result in more vegetation – and, in the case of peatlands, peat – loss than a low severity wildfire.

Wildfire *severity* risk is the focus of this report and a measure of the potential for a fire in a given location to become severe. This is distinct from wildfire *ignition* risk, which is derived from a combination of factors, both environmental and human-caused, including persistent drought, accumulation of flammable fuels, environmental humidity, human activity and development. There are existing reports that focus on ignition risk that contribute to the debate on wildfire risk, including MFFP's ignition risk assessment for the Peak District National Park (Dixon & Chandler, 2019). In the context of other work to better understand wildfire, this work contributes to the wider body of knowledge to aid decision-making around how to anticipate and mitigate against wildfire.

This report is based on blanket bog areas within the Calderdale Metropolitan District boundary, which were assessed using a mixture of desk-based surveys (using existing data sets) and on-the-ground surveys to ascertain the condition of the Blanket Bog. Recognizing the need to compare a range of factors in determining fire severity, Moors for the Future Partnership, in consultation with academics, fire and rescue personnel and land managers, developed an innovative severity matrix that builds on the matrix developed by the upland management group in 2019 to assess wildfires. This ground-breaking approach involved identifying the impacts a number of static factors and sub-factors have on wildfire severity risk, including both abiotic and biotic components of the landscape such as topography and vegetation.

Survey Results

The results show that 79% (8,740 ha) of the areas surveyed within the Calderdale area currently sit within the medium- to high-risk bands for severe wildfire., With the predicted impacts of climate change, there is potential that this could increase to 85%. As wildfire potential becomes more common and severe, the cost of restoring the damage is also likely also increase, alongside a greater risk to human health.

In total, the deep peat areas of Calderdale are estimated to emit approximately 29,871 tonnes of CO_2e (carbon dioxide equivalents) per annum, unless restoration is undertaken to change this. Most areas of Calderdale are estimated to be acting as a source of CO_2e, with a small area estimated to be acting as a sink.

Aside from impacts to carbon loss, biodiversity and the local economy, vegetation loss from such fires can lead to an increase in downstream flood events as catchment surface roughness decreases, allowing water to flow more quickly from the uplands. A decrease in water quality would also result from more peat being washed into watercourses and reservoirs. Wildfires can also lead to increased carbon loss, a threat to biodiversity and impact on the local economy – through damage to farming and shooting interests and to access from the general public.

The state of blanket bog was compared to the total wildfire severity risk score, to see if there was any correlation between the two variables. When looking at all states of blanket bog for all wildfire severity risk types, no statistically significant relationship was detected between these two variables. However, both variables were used to help prioritise areas for future restoration, as each variable independently indicates a level of need. Therefore, combining both variables works as a robust prioritisation tool.

Key recommendations

The report recommends that detailed site-specific surveys are undertaken to determine the exact nature and locations of the different restoration interventions that could be installed on the sites. Permission from the landowner and tenants, both to undertake the survey and undertake the capital works, would be required, alongside relevant consents from Natural England, archaeological bodies, and the council.

If we then apply the results of the wildfire severity assessment, which identified that 79% (8,740 ha) of the survey area was at medium or high risk, this would point to a possible restoration funding requirement of circa £12m (£15,365,085 x 79% = £12,138,417) to address the high- and medium-priority areas.

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1. Introduction

Calderdale Natural Flood Management Group commissioned Moors for the Future Partnership (MFFP) to assess blanket bog condition and wildfire severity in the Calderdale metropolitan area. This study delivers against action NFM52 in the Calderdale Natural Flood Management (NFM) Action Plan, managed by the NFM Operations Group:

"Enhance the resilience of habitats in the catchment against future risks such as climate change and wildfire – considering likelihood and severity of the risks; protecting all associated outcomes, NFM, clean water provision and storage, carbon capture, biodiversity, local economy and community."

1.1 Peatlands

Historically, blanket bogs of the South Pennines have been degraded from commercial afforestation, outbreaks of wildfire, and atmospheric pollution. Together, these influences have caused the loss of key vegetation species, including Sphagnum moss, which has subsequently led to a reduction in the water table (Allott et al., 2022) and, in turn, loss of the conditions which protect the accumulated peat and maintain blanket bog habitat. This historic degradation has resulted in negative impacts on a number of ecosystem services, from increased flood risk to an increase in carbon being emitted. Peatlands in this degraded state need to be restored both to protect the peat carbon stores and reclaim the ecosystem service benefits they are capable of providing.

1.2 Wildfire

One significant threat to this habitat is wildfire, which can cause a number ecological and societal problems, including air pollution, degradation of water quality, loss of species and habitats (Belcher et al., 2019, Glaves et al., 2020, McMorrow et al., 2009), as well as increases in carbon emissions that contribute to climate change (Worrall, 2022). Further, it is likely that the impacts of wildfire will increase in the future under climate change projections, and potentially due to the availability of certain moorland management techniques. The latter refers to the practice of burning heather on deep peat in protected Sites of Special Scientific Interest (SSSI) sites having been removed under the Heather and Grass Burning Regulations, 2021 (2022, Game and Wildlife Trust).

1.3 Wildfire Severity

This study focuses on wildfire **severity** risk. Wildfire severity is defined as the loss of, or change in, organic matter above ground and below ground (Keeley, 2009), and includes the secondary impacts such as subsequent soil erosion. In general terms, the severity of a fire is a function of its intensity and residency time, i.e. how hot it burns and for how long in a given location (Fire Science, 2022). In practical terms, the more severe a wildfire *risk* the more difficult it is to bring a fire under control. This is distinct from wildfire **ignition** risk, which is defined as a combination of potential environmental vulnerability factors and external hazard disturbances such as persistent drought, excessive accumulation of flammable fuels, environmental humidity, anthropogenic activity and human-made development such as infrastructure (Lin et al., 2022). Whilst there is a relationship between the two factors, for the purposes of this study they are treated as separate.

This study focuses on developing understanding of wildfire **severity** risk because of the particular threat it poses to blanket bog. It is important for those tasked with preventing and fighting wildfires, and with future planning and management, to identify where severe wildfires could take hold, what options are available if this happened and what might be done to reduce the risk of severe wildfire. This is because the impacts of wildfire vary (see Figure 1 and Figure 2) and the different factors that dictate the level of damage are not yet fully understood in a peatland context, based upon the evidence at the time of writing. Anecdotal evidence from practitioners within the peatland community and fire and rescue service suggest that vegetation species, aspect, slope and the presence of water, within the peat or pooled, all seem to have an effect.

Figure 1. The 2018 Roaches fire (Staffordshire) caused severe damage, destroying vegetation and approx. 5cm of peat across the burn scar, leaving a situation prone to erosion, carbon loss and high overland flow and leading to increased risk of flooding downslope and downstream.

Figure 2. Bare peat traces across the 2019 Bamford (Derbyshire) wildfire scar. It must be considered that revegetation and recovery are not determinants of severity; rather severity is one factor determining recovery. On Bamford, the steep slope may have heightened the severity but also will have hindered revegetation as sloping ground is less stable and therefore less easy for young plants to recolonise.

Surveys of Fire Operations Group members by MFFP, undertaken as part of the MoorLIFE 2020 project, indicated that there are perceived differences in the impact of land management and blanket bog restoration activities on reducing wildfire severity depending on the different habitat type. For example, applying heather brash to areas of bare peat was seen to increase the fire severity, because it introduced biomass to the habitat, whereas techniques that increased the water table height (e.g. gully blocking (see section 2)) reduced the perceived severity of wildfires on all states of blanket bog (Titterton et al., 2021).

1.4 Wildfire Ignition Risk

Whilst wildfire ignition risk is not the focus of this report, there are existing reports that focus on ignition risk and contribute to the debate on wildfire risk. In 2019, Moors for the Future Partnership investigated ignition risk in relation to a number of static factors, including public rights of way, settlement locations, previous wildfire locations and car park locations in the Peak District National Park (Dixon and Chandler, 2019). The effects of these factors will have a similar influence on wildfire risk in Calderdale area, but a further study is required to cover this area.

When looking at wildfire ignition risk, in general, it is difficult to draw accurate conclusions from the available data, due to the number of missing variables. For instance, current data suggest that most wildfire ignition events are caused deliberately. However, 39% of all wildfire ignition risk instances do not have this data available, which could drastically sway the results. Again, the most common cause is exposure to naked flame, but this is only recorded in 13 instances out of a possible 448 for the South Pennine Moors Special Area of Conservation. Another limitation associated with this dataset is the accuracy of identified wildfire locations, as the location provided by the Fire and Rescue Service may not be the location of the fire. It could be the location of the forward command post, or even where the vehicles are parked. Again, this limits what we can say with any accuracy on the location of wildfires (Titterton et al, 2021).

1.5 Factors and Sub-factors

There are a number of different factors that impact upon wildfire severity. Some can be described as static factors, i.e. factors that do not change from day to day, for example topography and vegetation composition. Alongside static factors are dynamic factors, which are factors that change daily, for example weather. For this study, only static factors were considered within the assessment, since these can be determined and reliably compared from existing datasets and ground surveys without being confounded by conditions in a particular location on a particular date.

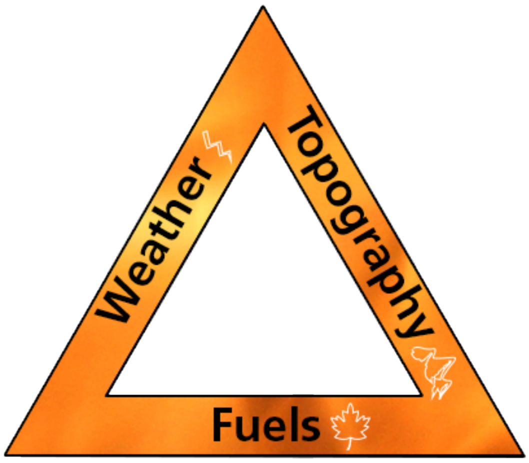
The factors can be further sub-divided into biotic and abiotic factors. Biotic factors include vegetation structure, height, uniformity and type, all of which can influence how severe a wildfire could become. For example, the structure of the vegetation dictates how easily it burns, with fuels below 6mm in diameter being classed as fine, and those more than 6mm in diameter being classed as coarse (Scottish Government, 2022). Fine fuels ignite most easily, contributing to intensity and spread, whereas coarse fuels can burn for longer, increasing residency time of the fire. A combination of fine and coarse fuels can lead to a fire of high intensity and residency time; a severe fire. Vegetation height, on the other hand, relates to how much total fuel is available (Glaves et al., 2020 and consultation, West Yorkshire Fire and Rescue Service).

Abiotic factors such as topography, soil moisture, slope and aspect also influence the wildfire severity risk. For instance, Estes et al. (2017) identified that east- and southeast-facing aspects tended to burn with higher severity than other aspects, due to them being dryer from increased exposure to solar radiation. Similarly, topographic features can influence fire behaviour, such as the rate of spread, with fires having the potential to spread most quickly on steeper slopes (Rothermel, 1972), and heading fires[1] more probable on the upper slopes than on lower-slope positions (Skinner et al., 2006). Topography also influences biophysical gradients such as solar radiation and topographic moisture, thereby altering fuel composition and availability for consumption (Holden et al., 2009).

1.6 Fire Behaviour Triangle

Estes et al. (2017) identifies that: "Topography, weather, and fuels are known factors driving fire behaviour, but the degree to which each contributes to the spatial pattern of fire severity under different conditions remains poorly understood." This work describes the behaviour of fire through what is known as the Fire Behaviour Triangle (see Figure 3), which comprises three key factors: fuel, topography and weather.

[1] Fire spreading in the direction of the wind or upslope, generally with higher intensity and longer flame lengths.



(US National Park Service, 2017)

Figure 3. Fire Behaviour Triangle

The work for Calderdale NFM Operations Group recognises the need to understand the landscape's fire severity risk through the factors highlighted by the Fire Behaviour Triangle and the other static and dynamic factors, but is targeted in its approach by limiting its scope to those factors that can be assessed within the scope of the project and the available evidence, Appendix I and section 4 methodology. It is anticipated that future studies will consider all three contributors to the Fire Behaviour Triangle to assist in more effective control of upland fires.

1.7 Blanket bog condition

For a blanket bog habitat to be classed as healthy it needs to have a number of key components, including:

- A range of key indicator species
- Abundant Sphagnum species
- A high water table (within 10cm of the surface for most of the year)
- Increasing decomposition deeper into the peat profile (Rezanezhad et al., 2016).

In order to ascertain the current condition of blanket bogs, Natural England and the Upland Management Group (UMG) developed the "Six States of Blanket Bog" guidance (Upland Management Group, 2017). The system uses a number of pre-defined criteria to assess and categorise the current condition of blanket bog (see Section 4.2) and attaches advice and intervention recommendations to help land managers move towards healthy (active) blanket bog from other states. It is recognised that blanket bogs in a healthy condition are more resilient to wildfire (due to the high water table and diverse vegetation structure), lose less carbon and are more biodiverse habitats (IUCN, 2011).

2. Ecosystem services

Healthy blanket bogs provide a wide range of ecosystem services, from employment through to flood risk management (Natural Environment Research Council, 2022). This section explores the ecosystem services upon which wildfire has the biggest impact.

2.1 Carbon

Peatlands cover 12% of British land surface, storing 3.2 billion tonnes of carbon (CEH, Unknown). As such, they will play a significant role in climate change, which could be beneficial or not. Blanket bog in good condition forms a carbon sink, sequestering carbon and storing it for millennia. When degraded, damaged or destroyed, peatland becomes a source of carbon emissions into the environment and atmosphere as the carbon that is locked up in the peat is lost through erosion (water and wind) (Nature Scotland, 2019).

In order to conserve and enhance carbon stocks in the ground, peat needs to be vegetated and very wet, which helps prevent erosion. With the majority of the moors being in an “unfavourable – recovering” condition (Defra, 2022), it is unlikely that these characteristics are widespread.

Recent computer modelling work undertaken by Worrall (2021) on the Durham Carbon Model, as part of the MoorLIFE 2020 project, indicated that conservation activities such as gully blocking, Sphagnum planting and bunding are the conservation actions that will have the biggest impact in reducing carbon losses from peatlands because they help to prevent sediment escaping from blanket bogs. Activities such as cutting heather, on the other hand, will have the least carbon benefit, but it is recognised that this can have other benefits for blanket bog ecosystems. The modelling work identified that, of the sites that had restoration work undertaken on them in MoorLIFE 2020, all sites would be greenhouse gas (GHG) sinks up until 2080 whereby, without further intervention, they would become a source of GHG emissions. This is difficult to quantify as there is large variation between sites, but it is estimated to be between 0.2 and 122 kg CH_4 ha^{-1} y^{-1} (Johannisson and Hiete, 2020). Research by Couwenberg (2009) indicates that methane emissions increase in recently rewetted blanket bogs as any newly submerged vegetation dies and decays. However, once the above-ground vegetation has decayed, anaerobic degradation decreases and, therefore, methane emissions decrease. This initial spike in methane production could be offset by planting species like *Sphagnum cuspidatum* (Larmola et al., 2010), which thrives in waterlogged conditions. Research by Kox et al. from the Netherlands in 2021, has shown that reintroducing Sphagnum into degraded bogs controls methane emissions despite raising water levels. Given that Calderdale blanket bogs are almost entirely assessed by Natural England as being in “unfavourable – recovering” ecological condition, they are unlikely to have high Sphagnum cover (Figure 4 below). In Calderdale there are also a number of SSSI units that are in an “unfavourable – no change” condition and some in an “unfavourable – declining” condition (DEFRA, 2022), which are likely to need even more attention to bring them into favourable condition.

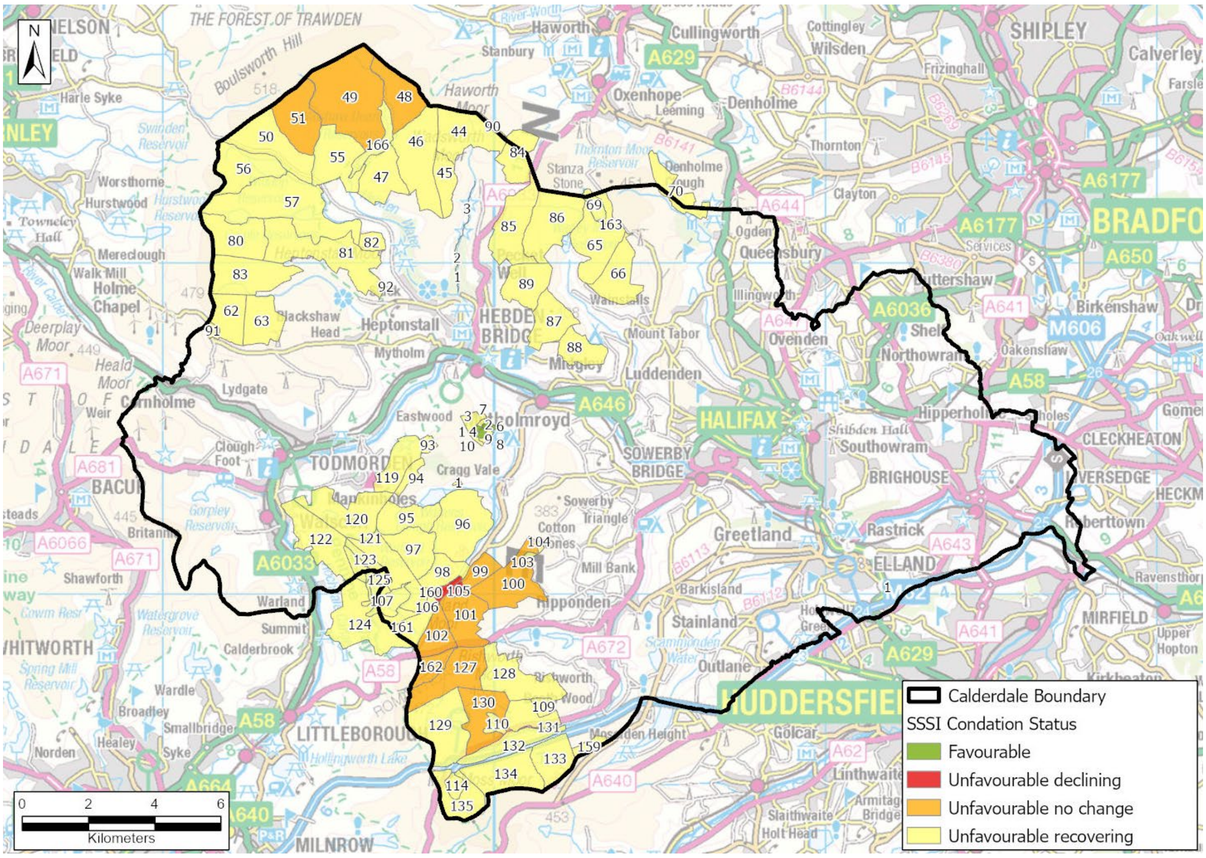


Figure 4. The status of blanket bogs on deep peat within Calderdale based upon Natural England's Common Standards Monitoring.

Unfavourable condition status indicates a lack of blanket bog indicator plant species, like Sphagnum mosses. Additionally, carbon stocks are held in vascular plants as well as the peat. At Moor House. a nature reserve covering blanket bog located in Teesdale in the North Pennines, this is estimated to be in the region of 3 t C ha^{-1} (Natural England, 2021), which is higher than the average for Marsden Moor, having just 0.3 t C ha-1 (Titterton et al, 2021a). In addition to the vegetation there is the carbon held in the peat itself that needs to be accounted for. As such, restoring the full vegetation associated with blanket bog, both the mosses and the vascular plants, which together help form and maintain the upper, active peat layer known as the acrotelm, offers the best chance for ensuring future blanket bog resilience in the face of climate change. The Natural England report continues to identify the different emission factors by the different states of blanket bog.

Table 1 Emission factors (EF) (t CO_{2e} ha^{-1} y^{-1}) for peat condition types (Natural England, 2021). Positive scores indicate carbon release, negative scores indicate sequestration.

Peatland Type	Emission Factors (t CO_{2e} ha^{-1} y^{-1})
Eroding Modified Bog (bare peat) (drained)	13.28
Modified Bog (semi-natural Heather + Grass-dominated) (drained)	3.54
Rewetted Modified (Semi-natural) Bog	-0.02
Near Natural Bog	-0.02

2.2 Water quality

Two thirds of English drinking water comes from the uplands (IUCN, 2009). UK water companies are continually investing in peatland restoration because of the critical role peat and blanket bog play in storing and cleaning the water provided to millions of people, by helping to filter out impurities and heavy metals as it moves through the peat (Irish Times, 2022), and reducing erosion which contributes to the loss of particulate organic carbon (Pilkington & Crouch, 2015). When peatlands become degraded, pollutants and peat can be washed into watercourses which can be costly to remove.

Yorkshire Water, amongst other organisations, has paid for restoration of blanket bog. An example of this is in 2012–14, MFFP delivered a £2.4 million project to restore Marsden Moor, a National Trust-owned site. This work was largely funded by Yorkshire Water for several reasons, not least because it was deemed more cost effective than to continually clean the water, sourced from this blanket bog, at the treatment works.

2.3 Flooding

Towns like Hebden Bridge have suffered extreme flooding events in recent years with much media coverage, due to the cost to human health and property. Hebden Bridge is surrounded by upland peatlands. Research has revealed that overland flow is accountable for up to 80% of water movement across such blanket bogs (Holden and Burt, 2003). This is because blanket bog in a damaged or degraded condition often lacks a moss layer, including Sphagnum, which, above the other species, greatly increases the hydraulic roughness of the ground surface and slows this overland flow (Holden et al., 2008). Without this roughness, water flows off these hills more quickly, which can overwhelm drainage systems in towns and cities (Darboux, 2014). While runoff production in upland blanket peat catchments is characteristically flashy, with large flood peaks and short lag times (Holden and Burt, 2003), Holden et al. (2008) showed that "Sphagnum provided a significantly greater effective hydraulic roughness to overland flow than peatland grasses." Yet it is grasses and sedges such as *Molinia caerulea* (Purple Moor Grass), *Nardus stricta* (Mat Grass), *Deschampsia flexuosa* (Wavy Hair Grass), and *Eriophorum vaginatum* (Hare's Tail Cotton Grass) which appear to cover more of Calderdale's peatlands than Sphagnum mosses.

However, fire can cause this flashiness to return, as analysis by MFFP (2022) on a site in the Peak District National Park called the Roaches, indicated that a severe fire caused the water table to significantly drop below its normal level, damaging the peat structure and causing the flashiness to return, mainly due to the loss of surface roughness. Currently it is unknown how long this damage is likely to remain.

Revegetating and rewetting, through the use of techniques like Sphagnum planting and gully blocking, is beginning to provide evidence that working with natural processes provides ecosystem service benefits (Allott et al., 2015). In 2017 the Environment Agency produced the Working with Natural Process (WWNP) evidence base, collating much of the evidence showing these benefits for Natural Flood Management (Hankin et al., 2017), yet already it is out of date, as further innovations are emerging. This includes work undertaken by MFFP and Manchester University on Kinder Scout showing that after restoration of degraded blanket bog, significant gains were made. Lag times increased by 106% and magnitude of flood peaks decreased by 27% after revegetation, and after a combined treatment of revegetation and gully blocking, lag times increased by 200% and magnitude of flood peaks decreased by 51% (Shuttleworth et al., 2019). This water in the upland landscape travels through, and is released from, restored blanket bogs more slowly into our river and drainage systems, and peak downstream water levels are reduced.

Gully blocking can be used to reduce the impact of flooding downstream of blanket bogs. Gully blocking techniques typically fall into one of two broad categories:

- Impermeable dams – designed to raise water table by forming permanent pools (thereby reducing soil oxidation and promoting growth of blanket bog vegetation including Sphagnum) – e.g. peat dams/ plastic dams.
- Permeable dams – designed to slow the flow and trap sediment – e.g. heather bales and stone dams.

Monitoring of the gully blocking work carried out by MFFP on Kinder Scout since 2011 has demonstrated the reliability of these techniques towards reducing flooding; 95% of gully blocks surveyed three years after construction were holding either water or sediment, or both (Maskill et al., 2015). The sediment that builds up behind permeable and semi-permeable dams will usually revegetate with cotton grass and other moorland species (Buckler et al., 2013). For example, Whitley (2010) found that of 391 gully blocks on Kinder Scout and Within Clough, only 11.5% had any gully floor vegetation behind them shortly after construction in 2004, whereas six years later, 85% of blocks had at least some vegetation. Thus, even when such dams have become engulfed by sediment build-up and no longer fulfil their primary function, they still support the revegetation of the channel, with an associated increase in surface roughness and consequent increase in lag time, and decrease in peak flow. Modelling, using data from the Making Space for Water project, suggests (Milledge et al., 2015):

- Restoration of 12% of the Upper Ashop catchment by gully blocking and revegetation can be associated with an average reduction in peak discharge of 5% at the 9 km^2 scale and revegetation alone with an average reduction of 2.5%.
- Restoration by gully blocking and revegetation can result in reduction in peak discharge of up to 12% and revegetation alone a reduction of up to 8%.

Additionally, a new trial on Close Moss conducted by MFFP under the MoorLIFE 2020 project, shows that degraded blanket bog sites can be rewetted and restored outside of grip and gully systems (Moors for the Future Partnership, 2020) by constructing bunds from peat, which hold water back. The bunds built on Close Moss are holding water for up to thirteen hours longer than on a control plot, while at the same time rewetting the peat and encouraging Sphagnum growth (which, once established, will further increase surface roughness and lag time). Added to this, the habitat these bunds create is beneficial for species such as golden plover, dunlin, curlew, dragonflies and water voles (see 2.4).

As Lead Local Flood Authority, Calderdale Borough Council has a duty to develop, maintain, apply and monitor a strategy for local flood risk management, and to specify objectives to manage flood risk and suggest measures to achieve those objectives (Calderdale Council, 2022). It can be seen that blanket bog restoration techniques assist in meeting these objectives.

2.4 Biodiversity

The blanket bog in Calderdale is valued and recognised for special features and qualities, through designations such as Special Areas of Conservation (SAC), Special Protection Areas (SPA), Environmentally Sensitive Areas and Sites of Special Scientific Interest (SSSI). These features of value include plant communities, such as those of ombrotrophic bog[2], and bird species such as curlew, golden plover, short-eared owl and merlin (Carr & Middleton, 2004).

However, "at the UK scale, the abundance and distribution of species has, on average, declined over recent decades and many measures suggest this decline continues" (Hayhow et al., 2019).

The blanket bogs of Calderdale broadly echo this national trend of failing health over the past century. Based upon the most recent surveys, which range from 2009 to 2022, the majority of

[2] Ombrotrophic bogs only receive nutrients, water and inputs from the atmosphere

blanket bog SSSIs are categorised as being in "unfavourable – recovering" condition by Natural England (Defra, Magic Map, 2021). A common reason for SSSI condition failing to be assessed as "favourable" is a lack of frequency and diversity of indicator plant species. As mentioned in 2.4, it is recognised that blanket bogs in a healthy condition are more resilient to wildfire (due to the high water table and diverse vegetation structure), lose less carbon and are more biodiverse habitats (IUCN, 2011). It follows that increasing biodiversity will increase habitat resilience and help move its condition towards being favourable.

Where restoration work through rewetting and revegetation has been carried out, for example at Turley Holes in Calderdale, the trajectory for such sites is likely to reflect the trajectories of improvement seen elsewhere, such as at Kinder Scout in Derbyshire. Indicator species, like Sphagnum, cotton grasses and dwarf shrubs, are returning to once bare and dry peat and the water is remaining on site for longer on restored areas of Kinder Scout (Allott et al., 2015). Alderson et al., in 2019, found that the establishment of vegetation cover on bare peat (i.e. increasing biodiversity), and the consequential development of surface roughness, are key drivers in rapidly reducing particulate carbon loss and attenuating stormflow.

3. Aims of the study

This study achieved the following objectives:

1. To identify areas of high wildfire severity on deep peat within the Calderdale area. This will highlight areas of potential concern due to the high severity risk associated with them.
2. To identify the state of blanket bog on areas of deep peat within the Calderdale area based upon the UMG's Six States of Blanket Bog.
3. To set out the current context of blanket bogs within the Calderdale area, with respect to carbon, biodiversity, policy and water resources including flood risk and water quality.
4. To provide an overarching view of the potential management interventions that could be undertaken in these areas based upon the above assessment.
5. To map the location of known water resources and access routes in the survey area
6. To provide wildfire mitigation recommendations, based upon the wildfire behaviour triangle.

4. Methodology

This study involved undertaking both desktop and on-site surveys to achieve the aims of the study identified above. This represents an innovative approach to surveying and mapping wildfire severity risk. It also provides the most accurate data available to inform this study and serve to inform future projects and initiatives.

4.1 Location of study area

The study specifically focuses on the deep peat within the Calderdale district boundary (see Figure 5). This comprises 12,768 ha of deep peat and includes a number of moorlands from Widdop in the North to Moss Moor in the South.

For this study, deep peat was defined as any blanket bog area that contains peat over 40 cm in depth (Walker et al., 2011), and its extent in Calderdale is based upon data provided by Defra (2021). Peat depth measurement did not form part of the ground survey.

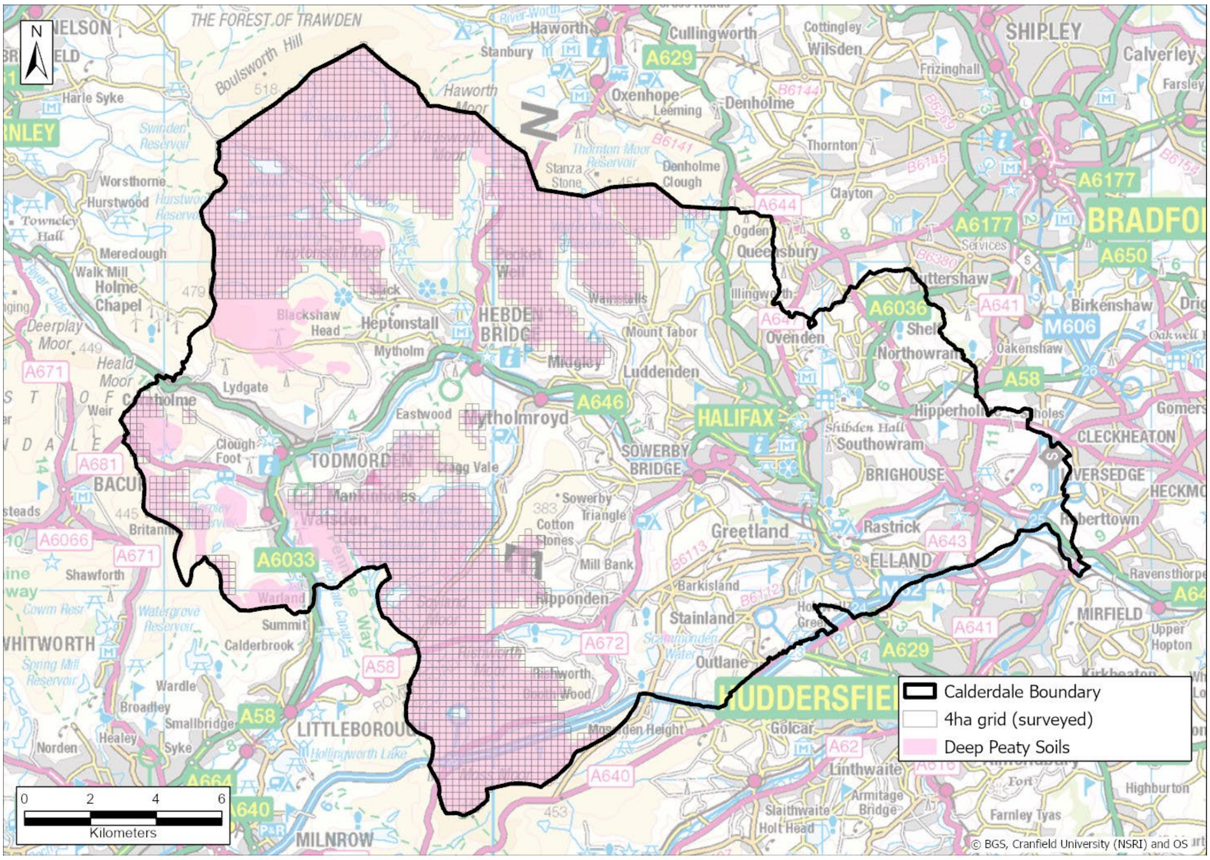


Figure 5. Location of study area.

4.2 Wildfire severity

4.2.1 Matrix development

In order to map the potential wildfire severity associated with deep peat, MFFP in consultation with Manchester University, West Yorkshire Fire and Rescue Service and Natural England developed an innovative severity matrix, shown in Appendix 1. Initially, the matrix included static and dynamic factors identified in section 1.4. These factors were identified from the academic literature, discussions with land managers and experts, as well as the experience of MFFP's Conservation Works Officers and Science and Monitoring Officers.

The matrix approach was chosen because the UMG Wildfire Management Guidance (2019) had previously used a matrix of factors as a means of assessing the ignition risks on a given site. Similarly, this study sought to consider multiple factors to assess potential wildfire severity risk, and the matrix approach was deemed the optimum way of doing so. Adopting a matrix approach similar to the UMG work provides some consistency of approach to assessment, which can aid with future work/ studies across different organisations as the collective knowledge base grows.

The matrix works by scoring each of the factors and sub-factors between -5 to +5 based on their perceived influence on wildfire severity risk. Negative scores represent a favourable impact on (i.e. decrease in) wildfire severity risk (e.g. the wetter an area is, the less chance there is of a severe wildfire occurring). Positive scores represent an unfavourable impact on (increase in) wildfire severity risk (e.g. a large fuel load would increase the risk of severe wildfire because there is more fuel for the fire to consume). A score for a factor can be applied or not based on the presence or absence of a factor.

4.2.2 Consultation

MFFP consulted on the draft Wildfire Severity Matrix with subject experts at the University of Manchester, Natural England and the West Yorkshire Fire and Rescue Service. Their feedback was sought on how, in their experience and knowledge, the factors and sub-factors could impact upon wildfire severity. Comments and references were also added where relevant.

Subsequently, the consultees above and MFFP's Conservation Quality Manager each scored the factors and sub-factors independently of each other. Blank spaces associated with a factor or sub factor indicated no clear opinion. There followed a discussion, led by MFFP's Conservation Quality Manager, to identify divergent scores and share evidence or views. This followed the Delphi method, recommended by a Lecturer in Environmental Management and Environmental Science at Sheffield Hallam University, in order to achieve consensus in a consulted group. "The Delphi method is a popular technique for forecasting and an aid in decision-making based on the opinions of experts, which has been in existence for over half a century" (Landeta, 2005).

Once a final score for each of the factors and sub-factors had been stated, this could then be turned into a series of "yes" or "no" questions, which would allow surveyors in the field to rapidly assess the sites' potential wildfire severity risk.

4.2.3 Field survey

The areas of deep peat were split into 4 ha squares (Figure 6). Undertaking the field survey at this spatial resolution meant that any variation on individual moorland could be captured, ensuring the results in the mapping outputs were meaningful in illustrating wildfire severity across the Calderdale landscape, in a "heat map" approach. The 4 ha spatial scale was chosen based upon experience of MFFP undertaking similar work on the Water Environment Grant (WEG)-funded Building Blocks project which aimed to map priority areas of hydrological restoration based on multiple factors, including the distribution of watercourses across the South Pennine Moors SAC. This project used GIS modelling to look at potential for pooling water on moorlands within the South Pennine Moors SAC, and represented results with a "heat map" approach, which provided a highly visual way of assessing the complex results that facilitated effective communications about these with partners and stakeholders.

When conducting the surveys between August and October, MFFP's experienced surveyors would walk into a 4 ha square to record the condition of the blanket bog and the presence or absence of factors and sub-factors within the square's boundary. When walking to and from the central point the surveyors noted the abiotic and biotic factors of the square, treating it like a survey transect. Where a grid square was not easily or safely accessible the data were collected from the nearest accessible point.

All data were recorded electronically using software called Survey123, which was loaded on to tablet computers prior to surveyors going out on site. The surveyors also used the ArcGIS Field Maps software, which allowed the surveyor to see their location in real time in relation to the survey grid, OS map background or aerial photographs. The program has a GPS accuracy of 4 m (Field Maps, 2022) which is well within the limits of each grid square. This stopped the surveyors potentially surveying incorrect grid squares.

To ensure consistency between surveyors, a series of training days were organised at the start of the survey period. This allowed surveyors to benchmark with one another the treatment (for field recording purposes) of any ambiguous characteristics where an element of estimation or judgement on the part of the surveyor was required. For example, that which (visually) would constitute an estimated 60% extent of a 4 ha recording square. A reference sheet was provided to the surveyors, which contained guidance on the recording of ambiguous characteristics, so they could refer back to it in the field. This ensured that there was a consistency of field data recording across the team of field surveyors.

Once the data were collected for each of the factors and sub-factors, they were checked for any inaccuracies, duplications and any outlying data within GIS and against Ordnance Survey base mapping and aerial photographs. Where duplicate records and records laying outside of the survey area were found they were removed from the dataset and not used in the analysis below.

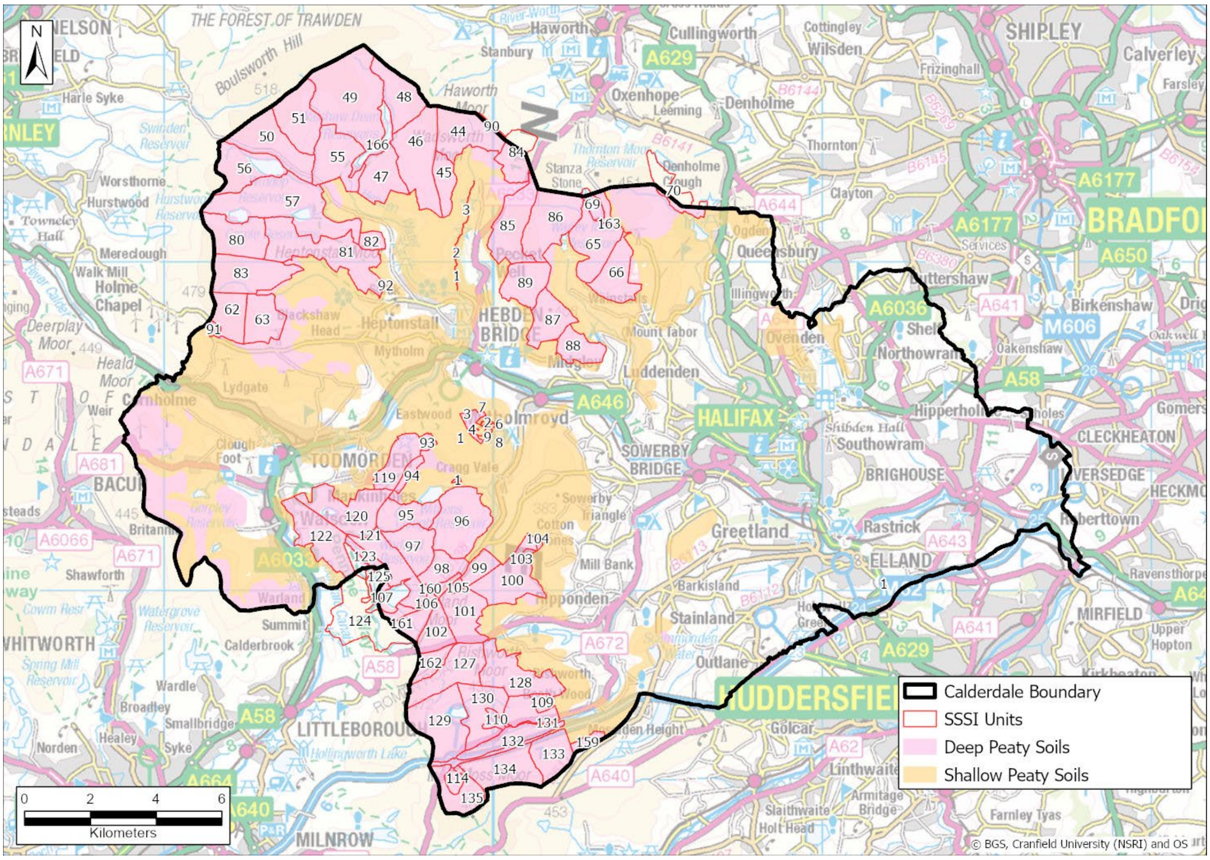


Figure 6. SSSI units overlaid over the deep and shallow peat layer. The numbers are those given to the individual SSSI units in the South Pennine Moors SSSI.

4.3 Blanket bog condition assessment

The blanket bog condition assessment was undertaken as part of the field survey work and was visually assessed by the surveyors according to the Six States of Blanket Bog based on the assumption that the Natural England deep peat data set was accurate. However, where it was clear that the square being surveyed could not be considered as blanket bog, for example, where the survey square comprised in-bye land or steep, rocky slopes, surveyors had the option to record a condition of "Not blanket bog". Figure 7 sets out the characteristics of the six different states of blanket bog.

State 1 relates to Afforested bogs, and Bogs which have been planted with trees, usually for commercial reasons, and are not functioning as blanket bogs. Therefore, they require a different restoration strategy (UMG, 2017).

Ref: UMG, 2017

Figure 7. The characteristics associated with the Six States of Blanket Bog

4.4 Access routes on to moorland areas

Tracks and roads accessible to vehicles typically used in fire response activities were also assessed through a combination of ground and desk-based (see 4.5) surveys. Consultation with West Yorkshire Fire and Rescue Service provided information and limitations relevant to access capabilities of three categories of vehicle used by the fire service: fire appliance, 4x4 SUV vehicle, and

UTV off-road vehicle. As well as recording information for the wildfire severity matrix, ground surveyors recorded point information along access routes encountered while moving within the 4 ha grid squares. The data recorded provided information on route surface types, widths, and any characteristics that might prevent progress for the different vehicle types, such as narrow gates or overhead obstacles. This point data was combined with Ordnance Survey road and track data to allow routes on to and across the survey areas to be categorised according to suitability for vehicle categories, i.e. fire appliance, 4x4 SUV or UTV, with a higher level of confidence than could be achieved through desk mapping alone (Figure 8). However, surveyors did not cover the total lengths of all tracks, which would have required hundreds of kilometres of walking in addition to an already ambitious survey scale. Additionally, not all tracks could be identified from maps, precluding a definitive travel and surveying plan. Where surveyors discovered tracks through undertaking the survey, they were included. As such, the assessment of routes included in this report is necessarily indicative and high-level, rather than a definitive guide on the suitability of routes. It should not be relied upon, therefore, for detailed planning of practical site access (see Figure 10 and section 5.3).

4.5 Desktop research

Table 2 outlines the factors and sub-factors surveyed using GIS alongside the publicly available data sets used. The decision to use GIS for these attributes was taken because it allowed more reliable results to be achieved than in the field at the necessary scale.

Table 2 Datasets used in GIS analysis by factors and sub-factors.

Factor / Sub-factors	Dataset
Access (road/ track/ path)	OS Open Roads OS Open USRN
Aspect	1 DTM LIDAR data
Slope	1 DTM LIDAR data
Soil moisture	Sentinel-2
Surface moisture (Water bodies location)	Spatial inventory of UK waterbodies

As soil moisture can vary, a relative, rather than absolute, set of values was needed. Sentinel-2 data was obtained from four separate dates (19/04/2020, 29/05/2020, 19/04/2021 and 08/06/2021) and an average of the soil moisture was taken and used for the wildfire total score analysis. These dates were chosen because they were cloudless days, allowing the whole of Calderdale to be assessed consistently on that day, and taken at the times of year wildfires are most likely to occur.

4.6 Total Score Calculation

Scores from the field and desktop surveys were combined to calculate a total wildfire severity risk score in a similar way to the Ipland Management Group's wildfire template (UMG, 2019). These scores were categorised into low, medium and high categories of wildfire severity risk. The categories were split in ArcGIS using natural breaks within the dataset based upon natural groupings inherent in the data. These class breaks are created in a way that most effectively groups similar values together and maximizes the differences between classes. The features are divided into classes whose boundaries are set where there are relatively big differences in the data values (ESRI, 2022). For this dataset, Table 3 below sets out the range of each classes.

Table 3 Category boundaries for the wildfire severity scores.

Category	Score
Low	1 – 12
Medium	13 – 18
High	19 – 29

4.7 Statistics

The total wildfire severity score (Figure 8) was compared to the states of blanket peat (Figure 12) to identify any relationship between the variables. To test for any detectable correlation between the severity scores and the Six States of Blanket Bog construct, a Chi-squared test was applied, to allow both discrete data and continuous data to be assessed (Urban Policy, 2022). To undertake this statistical test Equation 1 below was used:

$$\chi_c^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

X^2 = chi squared

O_i = observed value

E_i = expected value

Ref (Glen, 2022)

Equation 1 Chi-squared test

5. Results

5.1 Wildfire severity results

The maps presented below are based upon the total wildfire severity scores obtained from the field survey and desktop research. While included in this section for reference, full-sized maps are provided separately in Appendix 2. The analysis below includes all areas surveyed, equated to 2,755 survey squares (11,020 ha). This does not include all areas of deep peat in Calderdale. MFFP approached all identified landowners within the study area and permissions could not be secured for all landholdings. In total,1,748 ha of deep peat was not surveyed.

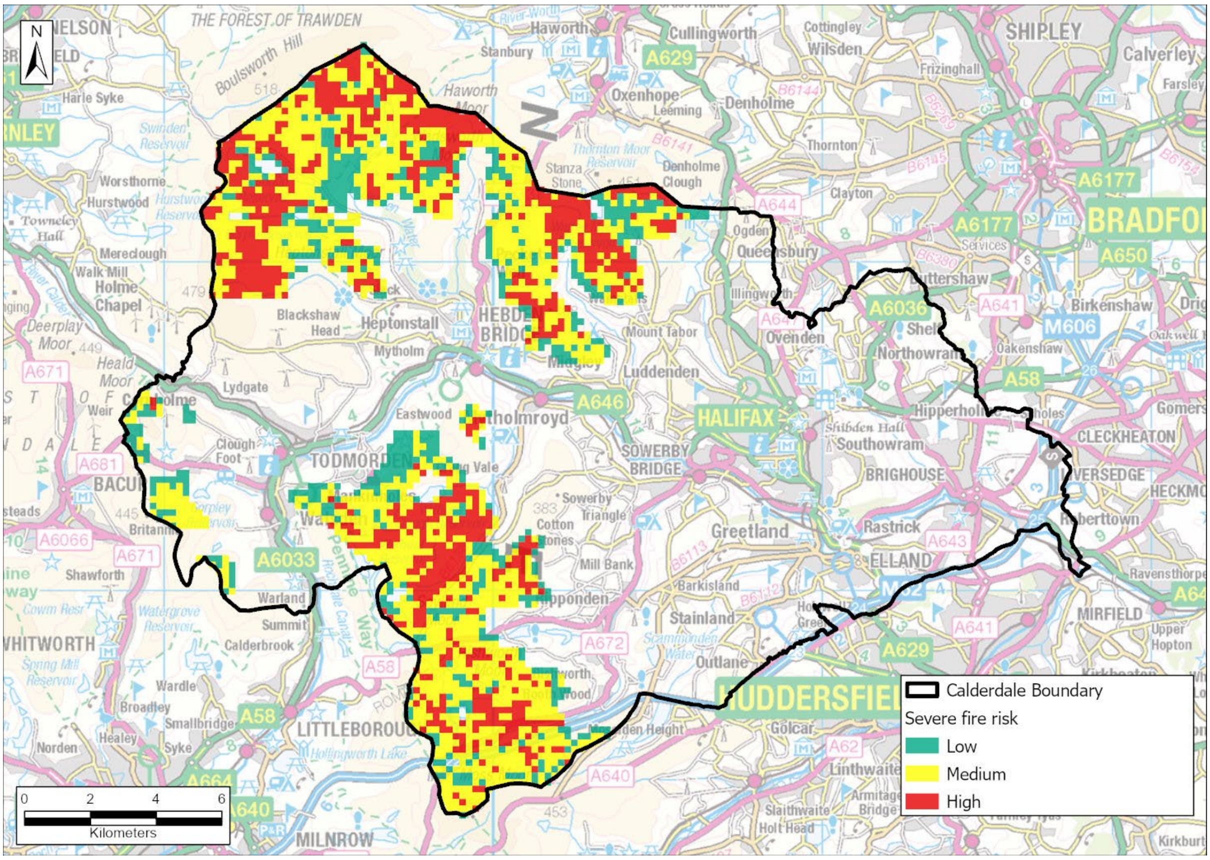


Figure 8. A map showing the wildfire severity for areas of deep peat in Calderdale Council's area based upon the aggregated scores of all the factors and sub-factors.

5.2 The distribution of wildfire severity

Figure 8 shows that the surveyed squares with potential for the most severe fires are located within the northern area of Calderdale. There is also another significant area of high wildfire severity found along the B6138 Turvin Road. In total, 828 survey squares (3,313 ha) were identified as a high severity wildfire risk across Calderdale. The most common fire risk severity category is medium, as it covers 1,357 squares (5,428 ha), which are spread across all areas of the Calderdale district. The least common fire risk severity areas are those categorised as low, with 570 squares (2,280 ha), and these are primarily around Todmorden and Walshaw Dean Reservoir.

The mean total scores associated with potential wildfire severity risk across Calderdale is 16, which would put Calderdale, taken as a whole, in the medium-risk category in terms of potential wildfire severity risk.

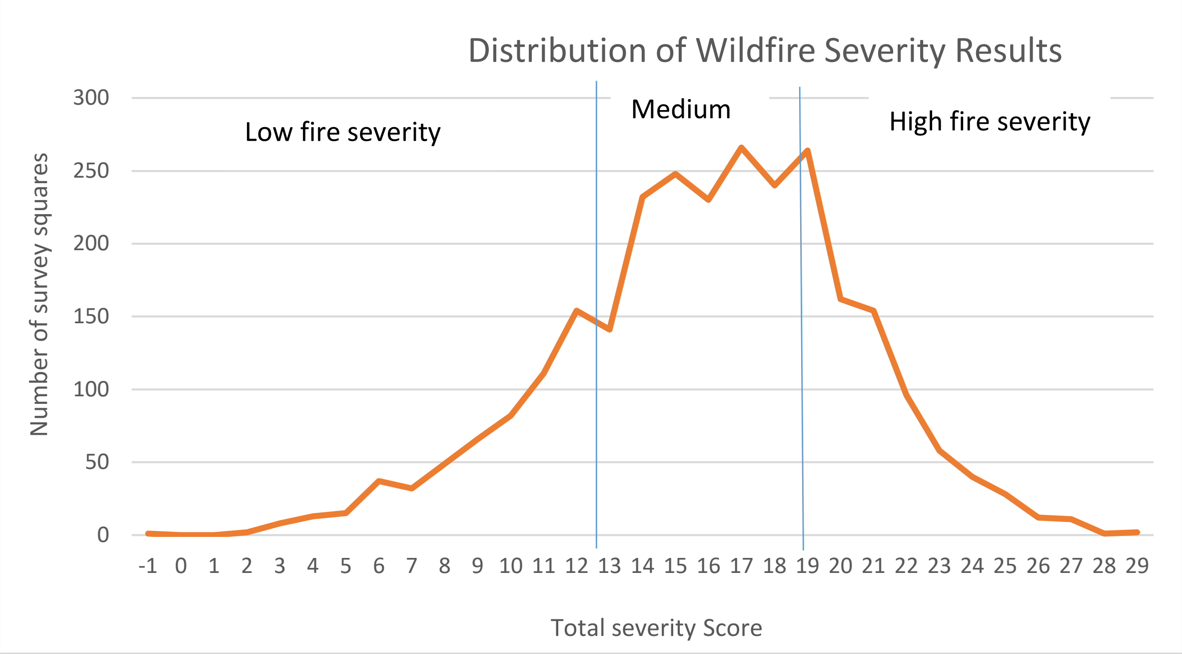


Figure 9. A graph showing the amount of survey squares by total score and severity category.

The map in Figure 10 shows significant tracks accessing the blanket bog areas of Calderdale.

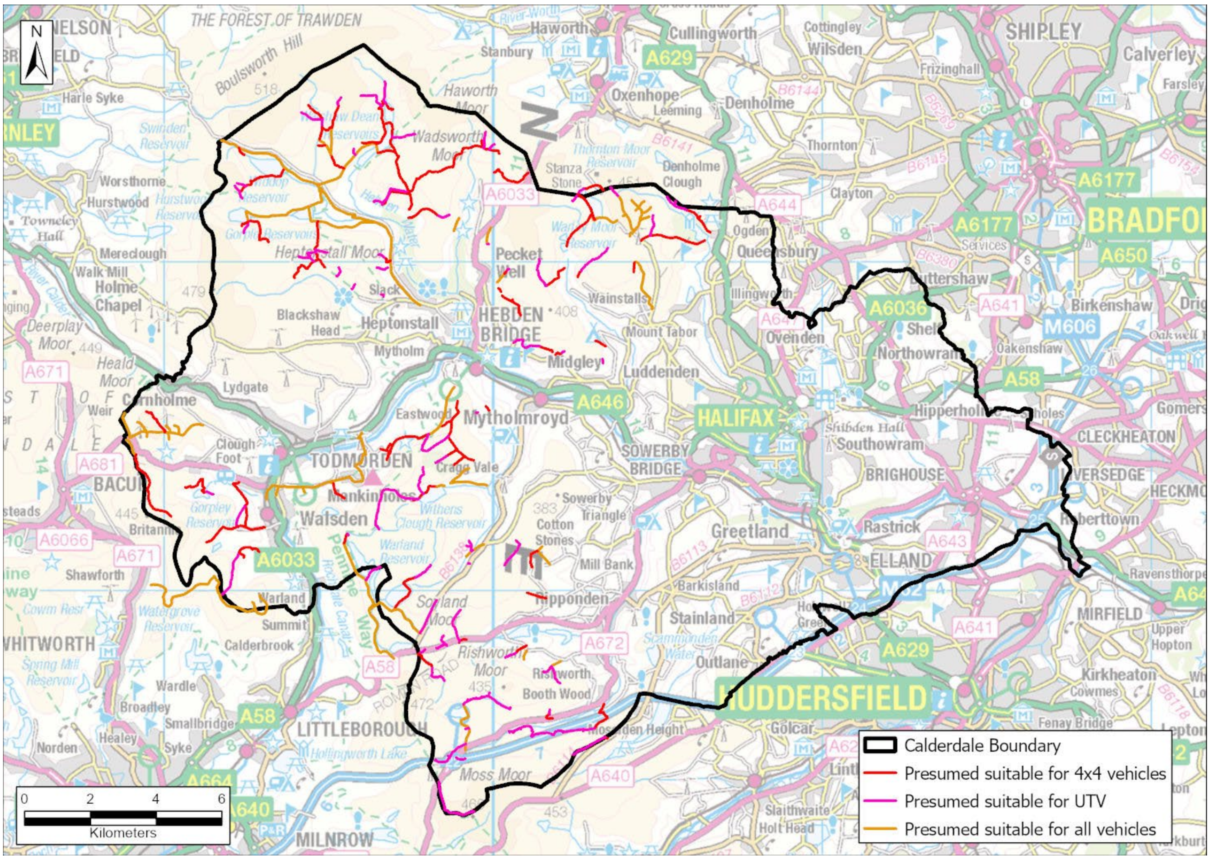


Figure 10. A map showing the access characteristics for areas of deep peat in Calderdale Council's area, based upon ground-surveyed point data and OS data. MFFP has no control over access on to these sites or the routes themselves. The assessment of access routes has been looked at for the sole purpose of informing this project. The map is not to be used to plan land access by third parties and no formal

feasibility of access test has been made as part of this project. Any and all access permissions would need to be sought from landowners and stakeholders.

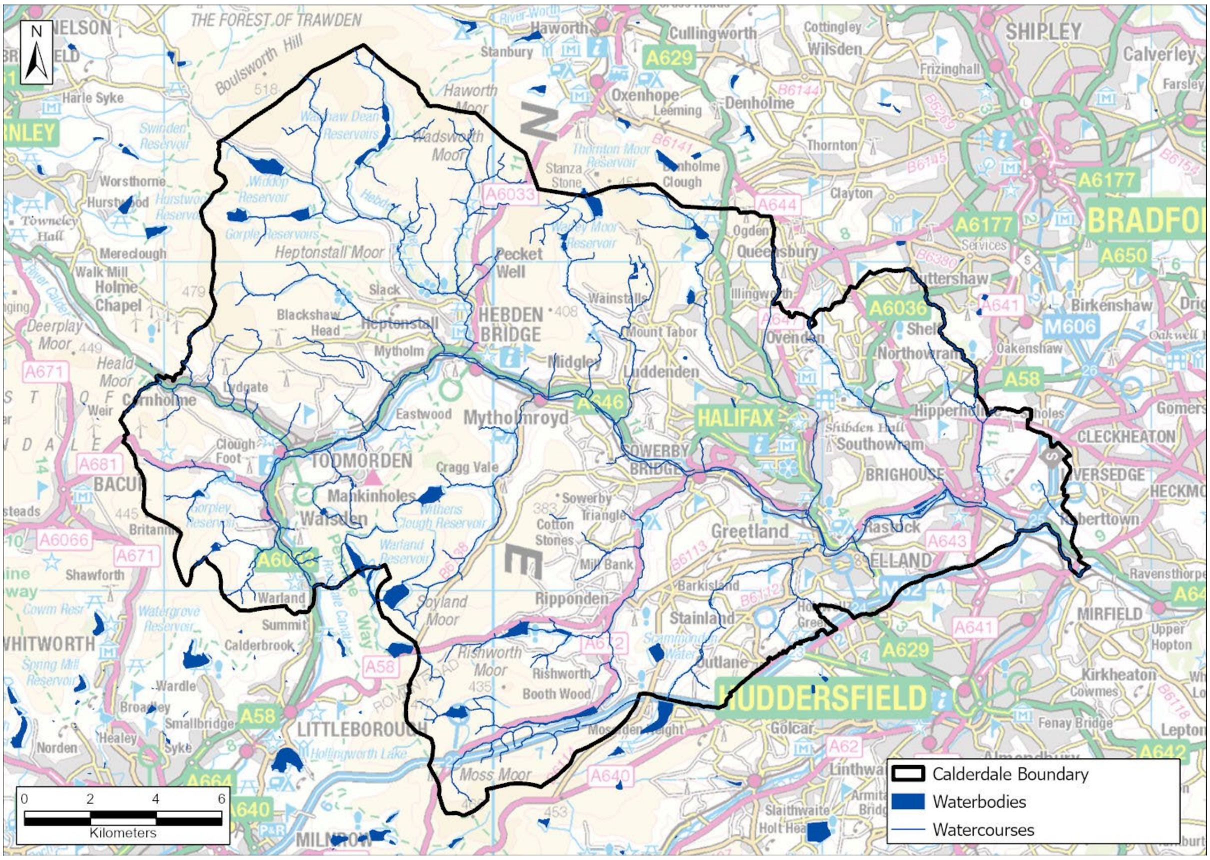


Figure 11. A map showing the large water bodies within the Calderdale area that are persistent throughout the year.

The large water bodies identified throughout Calderdale are shown in Figure 11.

5.3 The Six States of Blanket Bog

The maps below show the surveyors' assessment of the state of the habitat.

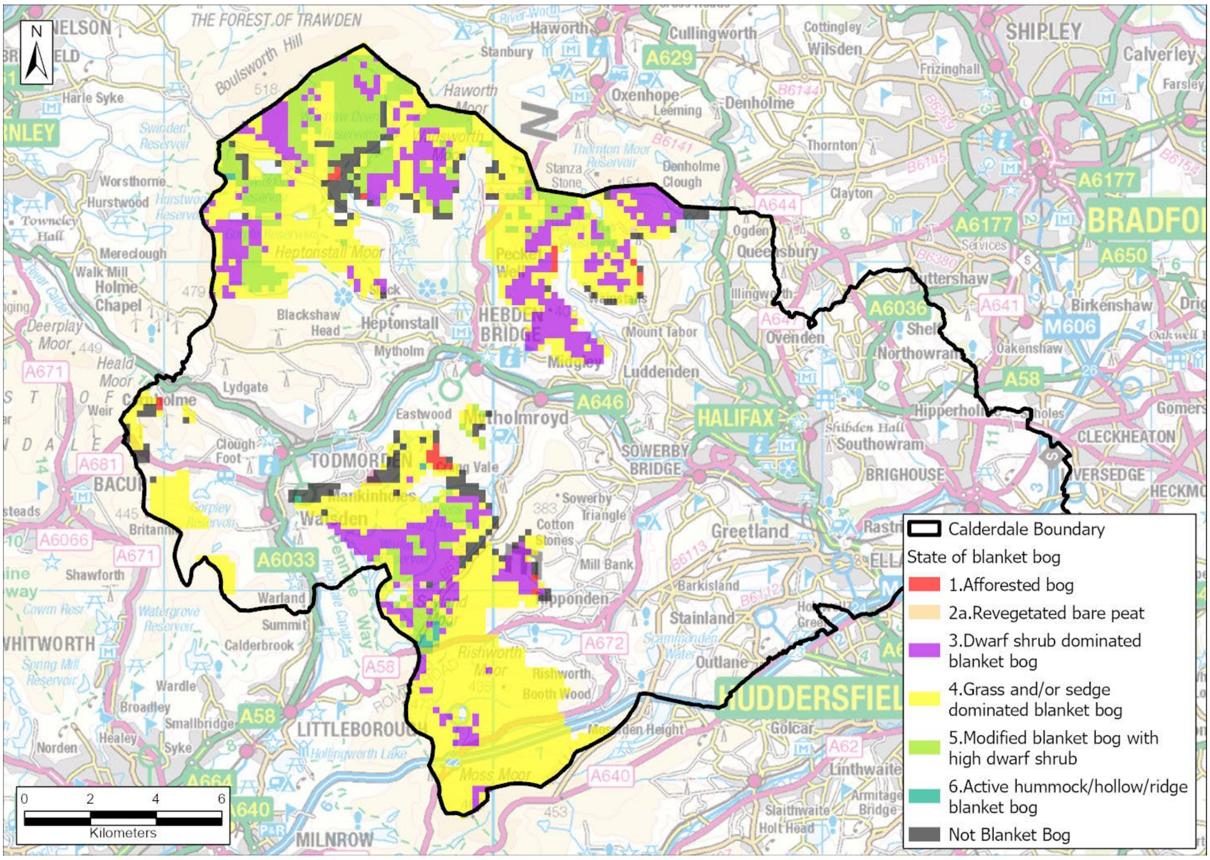


Figure 12. A map showing the state of blanket bog based upon the UMG's Six States of Blanket Bog assessment.

Figure 12 above shows the distribution of the different states of blanket bog, with the majority of State 3 being located within the northern and south west area of Calderdale. In total this state covered approximately 2,366 ha (see

Table 4). The predominant state of habitat found across the Calderdale area is State 4 which covers 6,092 ha, and is found throughout the Calderdale area. The least extensive state of blanket bog identified is State 2, with no survey squares identified within the survey area.

It is worth noting that there is 28 ha of State 6 blanket bog habitat focused on Soyland around the Turvin Road area. However, there are also a number of other isolated survey squares in the Calderdale area that fall into this category. For example, 8 ha west of Widdop Reservoir. The implications of the presence of State 6 blanket bog are discussed in section 6.4.

Table 4. The proportion of blanket bog in the Calderdale area split by the different states of blanket bog

State of blanket bog	%	Area (ha)
1	0.8	96
2	0	0
2a	0.1	20
3	21.1	2,336
4	55.2	6,092
5	15.0	1,644
6	0.34	44
No blanket bog	6.9	768
Total	**100**	**11,020**

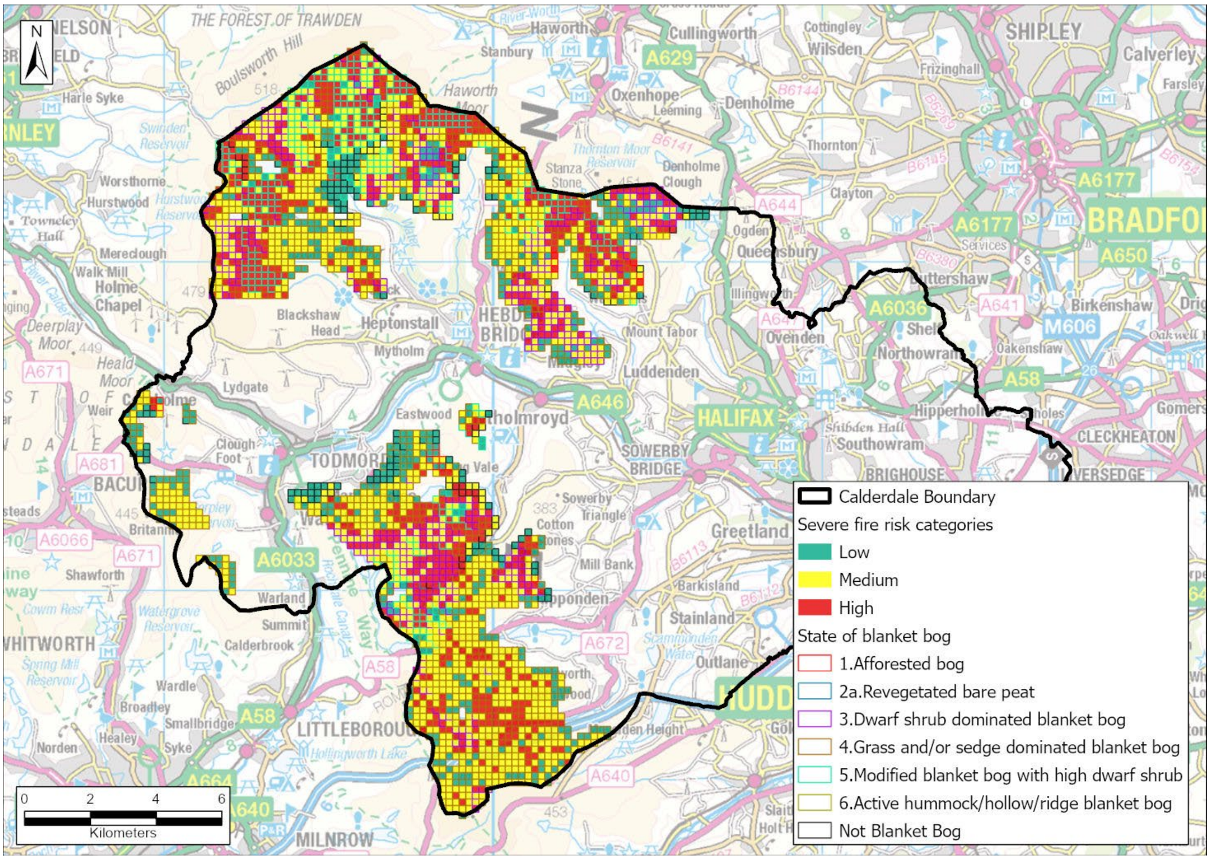


Figure 13. A map showing both the Six States of Blanket Bog and wildfire severity for areas of deep peat within Calderdale Council's area. This information is presented as two maps in Appendix 2.

Figure 13 above provides a comparison between the different states of blanket bog and wildfire severity risk for the Calderdale area.

5.4 Limitations of the study

There are a number of limitations inherent when evaluating wildfire behaviour, in general, and the factors influencing wildfire severity risk particular to this project. Those that relate to this study include:

- The aggregated wildfire severity risk score is an indication and guide to how severe a wildfire could become if the correct conditions exist at the time of the ignition event. This is because there are a number of dynamic factors, such as weather (e.g. time until it rains, wind speed and direction, etc.), and how long it takes for the fire to be identified and the subsequent response time by the relevant Fire and Rescue Services, land managers/game keepers, that affect how severe any given fire could become. As these factors will vary, it becomes difficult to quantify how this will affect wildfire severity and consequently these dynamic factors are not within the scope of this study. The study has primarily focused on the static factors (e.g. vegetation type) and that influence the probability of a severe wildfire occurring and that can be surveyed and quantified.
- Once a fire has started and been identified, there are also a number of practical variables that could have influence upon how severe it becomes, including what equipment and funding is available to tackle the wildfire event. This is because different landowners and tenants have different equipment and training used to tackle wildfires. Furthermore, the use of aerial firefighting equipment can help tackle large fires but is expensive and landowner budgets may not be available to provide this facility. The assessment undertaken for this report did not include an audit of firefighting equipment, personnel or financial resources available to specific land holdings, and the results should be viewed with that in mind.
- The resolution of the Sentinel-2 data meant that, when mapping the water bodies, the smaller pools and water sources, for example those behind the gully blocks, could not be identified. This is because the pool of water created by a gully block is too small to be seen in the data set. These pools can be important as they help to rewet moorlands, act as breaks for wildfires and provide a source of water for backpack water pumps that are used by the fire and rescue service. Nevertheless, as they could not be identified from the dataset, surface water coverage was excluded as a factor from the wildfire severity score. This could potentially reduce the wildfire severity scores. However, it would only reduce the severity slightly due to the influence the gully block will have on the Water table.
- Ground surveyors recorded the presence of a moss layer as part of their vegetation assessment. However, extent of Sphagnum cover was not specifically recorded as this would have been impractical at the 4 ha scale. Sphagnum cover will have a significant effect on wildfire resilience but, in general, is low across the South Pennines outside of localised pockets at less than the 4 ha scale or areas of State 6 blanket bog (see 6.4) In State 6 areas, Sphagnum cover will be relatively high, with other states containing varying degrees of cover according to their level of degradation.
- Detailed peat depth measurement was beyond the scope of this project. Instead, the area indicated in the Natural England deep peat dataset was used to indicate the extent of deep peat. Since peat is a fuel itself and its depth and extent will be important to understanding the magnitude of the carbon stores to be protected in Calderdale, not having this information limits how quantitative and complete a peatland inventory can be.
- As covered in 4.4 and the caption for Figure 10, the surveying of access routes did not cover the whole length of all tracks and roads. As such, the suitability of access for vehicles given in Figure 10 is indicative only, since obstacles to progress (narrow gates, tight turns, low tree branches, etc.) may exist on part of the route not visible to or covered by surveyors. Unidentified obstacles to vehicle progress are more likely to be present at the moorland fringes,

where more boundary walls/ fences and overhead obstacles are generally found, as opposed to open moorland.

6. Discussion

6.1 Wildfire severity

The results indicate that 79% (8,740 ha) of the areas surveyed within Calderdale currently have medium to high wildfire severity risk. Looking forward there are a further 154 survey squares (616 ha) that are just

one point below being classed as a medium wildfire severity risk, and 240 survey squares (960 ha) just one point below being classed as high wildfire severity risk. Therefore, without intervention and with the predicted impacts of climate change, there is the potential that Calderdale will see more wildfires and more severe wildfires in the future. In turn, this could lead to a potential increase in impacts such as flooding as surface roughness decreases, and a decrease in water quality as more peat is washed into watercourses and reservoirs.

6.2 Economic impacts

As wildfire potentially becomes more common and severe, the costs to restoring the damage from them is also likely to increase. Currently, it is estimated that for Stalybridge, where a fire covering approximately 1,000 ha occurred in 2018, restoration costs can be up to £1 million (Manchester University, 2022), excluding the socio-economic impacts that wildfires can have, this can include the losses to local business, firefighting costs and costs of having to shut transport networks (Belcher, 2012).

Wildfires also pose a threat to human health, which has an economic impact. Work undertaken by Graham et al. in 2020 identified that the large Saddleworth fire had an impact of up to £21.1 million based upon the short-term mortality burden due to exposure to Particulate Matter 2.5 that were above the recommended average by the World Health Organisation for at least one day.

6.3 State of blanket bog compared to Wildfire Severity Risk

The state of blanket bog was compared to the total wildfire severity risk score, to see if there was any correlation between these two variables. Figure 13 suggests that there is weak correlation between the individual states of blanket bog and wildfire severity. For example, more than half (55%) of State 4 bog sits in the medium risk category, while less than 1% of State 6 sits in the high risk category). However, when looking at all states of blanket bog for all wildfire severity risk categories, the Chi squared test detected no statistically significant relationship between these two variables as the X^2 value is 271.5 with a "*p*" value of 1.41.

When drawing conclusions on what the results tell us with respect to any relationship between the condition of blanket bog and its risk of severe wildfire, it is important to consider what the data being tested are based on: the Six States of Blanket Bog construct and the wildfire severity risk score derived from the survey matrix, both collected at a resolution of 4 ha.

The Six States of Blanket Bog deliberately conceptualises and simplifies complex ecosystems into a handful of categories describing an overall character that can readily be assigned on the ground according to easily observable characteristics; it is primarily a visual assessment and there is a level of subjectivity within that that one might expect to increase as spatial scale increases. Despite the discrete categories, the reality is that the character of blanket bog habitats is determined from numerous factors on a continuous spectrum, not all of which are easily assessed by eye. Two areas of the same state could, therefore, be quite different from one another. Likewise, two areas assigned different states could be similar by some measures. In the context of limitations inherent within the Six States of Blanket Bog construct, the survey resolution and those given in section 5.3, then, the lack of a detectable relationship between state and wildfire severity cannot be reliably extrapolated to a conclusion that there is no strong relationship between the *condition* of blanket bog and its risk of severe wildfire. To confirm the presence or absence of a relationship between the level of degradation of blanket bog and its risk of severe wildfire would require testing the latter against data derived from more detailed measurement of the primary environmental variables that determine the condition of blanket bog.

Even though no statistical relationship was detected between the two variables, both variables can be used to identify potential priority areas for future restoration. Table 5 below provides a simple overview of the order of prioritisation in which areas should be restored, with those coloured red being prioritised first. This is because they have high wildfire severity risk, potentially causing the most impact, and these survey squares also require restoration to include abundant Sphagnum, some cotton grasses and a range of dwarf shrubs (UMG, 2017). Whereas, those coloured amber are of a medium priority due to having some potential wildfire severity risk and requiring less intensive restoration work to increase them to a favourable condition. Those coloured green have a lower priority as they have a limited wildfire severity risk and are further along the pathway to restoration. It is recognised however, that this is a simplified approach and that detailed on-ground surveys are required to get a more precise picture of the restoration requirements per site, and further engagement would be needed to achieve consensus and commitment from all stakeholders on any proposed restoration. Likewise, restoration plans should be cohesive at the landscape scale. Those shaded dark grey are not included in this analysis because they are not blanket bog or require a different approach to restoration (afforested bogs).

Table 5. Priority classes for restoration and ha of each severity type by the Six States of Blanket Bog.

		Fire severity by category (ha)		
		Low	**Med**	**High**
Blanket bog wildfire severity	**1**	40	36	20
	2a	12	0	8
	3	144	1092	1100
	4	1436	3372	1284
	5	128	716	820
	6	8	32	4
	Not blanket bog	512	180	76

6.4 Blanket bog condition assessment

Analysis of the different states of blanket bog shows that no State 2 bog was identified in these surveys, which is positive for the Calderdale area, as this means that there are no large areas of bare peat that require restoration. It also has a number of benefits from an ecosystem service perspective, including limiting the amount of carbon being released from the habitat and the increased surface roughness reducing flood risk downstream. However, it does not mean that bare peat is not present. Instead, it's a reflection of the spatial scale of the survey (4 ha).

The different states of blanket bog are clustered into areas, suggesting a continuous sward height and structure. This could aid the spread of wildfire across the habitat making a wildfire event more severe by allowing it to cover a larger area quickly, if the correct conditions persist. It is therefore suggested that restoration techniques that change the height of the sward and make it wetter (e.g. Molinia cutting with planting of Sphagnum into the cuts to create firebreaks) would be beneficial.

Only 0.3% (44 ha) of the blanket bog assessed are in State 6, which is the target state for blanket bogs. The State 6 identified by the condition assessment corresponds with the blanket bog identified as being in favourable condition by Natural England. While likely to be more resilient to wildfires and climate change, and quicker to recover from wildfire events, these areas should be protected, as far as possible. This is important for the ecosystem services that they already provide, but also because maintaining habitat in good condition allows resources that might otherwise be needed to restore it after a fire to be allocated to the restoration of areas in a more degraded state in order to extend and increase that habitat resilience. These State 6 areas may be subject to other pressures that risk causing a decline in their condition, however. For example, a State 6 area surrounded by drained or degraded bog that affects the stability of the water table into the State 6 area may put both areas on to a trajectory of decline. The overall trajectory of State 6 and adjacent areas should be factored into decisions over restoration priorities, whereby protecting these areas and restoring adjacent areas could be considered the most readily achieved option for investment in terms of increasing the extent of active and resilient blanket bog.

In total it is estimated that there are 12.8 million tonnes of carbon locked up in the moorlands of Calderdale, based upon the proportion of blanket bog area in Calderdale compared to the whole of the UK (CEH, Unknown). Based upon the hectares of the different blanket bog sates, Table 6 determines whether the bogs in Calderdale are currently either a sink or source for GHG emissions and estimates the potential losses and gains using figures given in Table 1.

Table 6. Total hectares of deep peat in the Calderdale area split by the State of blanket bog, and the associated carbon emission values.

Peatland Type	State of blanket bog	Emission factors (t CO_{2e} ha^{-1} y^{-1})	Area (ha)	GHG emissions (t CO_{2e} ha^{-1} y^{-1})
Eroding Modified Bog (bare peat) (drained)	State 2	13.28	0[3]	0
Modified Bog (semi-natural Heather + Grass dominated) (drained)	State 2a, 3, 4	3.54	8,448	29,905.9
Rewetted Modified (Semi-natural) Bog	State 5	-0.02	1,664	-33.2
Near Natural Bog	State 6	-0.02	44	-0.8
Total				**29,871. 7**

Table 6 identifies that, in total, the deep peat areas of Calderdale are estimated to emit approximately 29,871 tonnes of CO_2e (carbon dioxide equivalents) per annum, unless restoration is undertaken to change this. Most areas of Calderdale are estimated to be acting as a source of CO_2e, with a small area estimated to be acting as a sink.

[3] See note about the survey's spatial scale in 6.4.

7. Recommendations

This study has used a novel approach to provide a high-level assessment of potential wildfire severity risk for the majority of deep peat habitats present in the Calderdale area. This is set within the context of the observed condition of the blanket bog habitats using the UMG Six States of Blanket Bog as an indicator of the presence/ absence of degradation within the habitats. This provides a means of contextualising the likely restoration needs within the landscape as linked to both future habitat resilience (including wildfire impacts) and ecosystem function and service provision.

Whilst high-level by design, this approach provides a meaningful framework to use as a starting point from which to approach the prioritisation of restoration needs from the perspective of wildfire severity risk, to be viewed in combination with other relevant considerations. The outline recommendations in this section are based on the findings of the assessment and support the established wider case for blanket bog restoration at scale.

For illustrative purposes at this pre-restoration planning stage, MFFP have included some high-level financial illustrations of cost scenarios based on their experience of delivering landscape-scale peatland restoration. This information is for illustrative purposes to create visibility for the potential maximum capital costs of restoration across the whole study area, and within the levels of priority suggested by the findings of the study. Further to this, additional site-scale context on the likely costs of restoration is provided to aid the transference of thinking on costs to future applied situations, with a view to next steps and planning for future peatland restoration in the area at scale.

The following section makes two key recommendations coming out from this work:

1. Undertake detailed restoration planning and surveys on priority areas identified.
2. Work in partnership to develop a joined-up funding strategy for peatland restoration in the Calderdale area.

7.1 Restoration interventions

From this study, MFFP recommends detailed site-specific surveys using a prioritised approach surveying sites in line with the wildfire severity risks identified and all other relevant site information. This detailed survey work would determine the exact location and extent of the different restoration interventions required that could be taken forward on the sites. It is recommended that for any restoration interventions and ongoing management to be planned, the key objectives emerging from this study are:

- To place/maintain the habitats on a positive trajectory toward favourable condition and active blanket bog status (State 6)
- Where possible, to reduce wildfire severity risk in high-risk areas
- Where possible, to prevent fires started elsewhere from reaching areas at high risk, i.e. interrupt the connectivity between high ignition risk locations (where these are known) and high-severity-risk locations

In terms of wildfire, restoration interventions are a means of changing the factors significant to wildfire severity that there is a level of control over: vegetation (fuel) and moisture. While other factors are important, the ability to change them might be limited or non-existent; steepness of slope, for example.

Any restoration planning to be taken forward will require periods of focused engagement with stakeholders and the relevant permissions from the landowner and tenants, to enable both the survey and the restoration capital works, and to ensure that ongoing land management will be consistent with the outcomes achieved by these works. In addition to this, consultation with and co-production on proposals will involve Natural England, who will also have a consenting role for any proposals to be brought forward to delivery. Archaeological bodies, and the council would also need to be consulted with and all necessary consents obtained before any restoration works could be scheduled. Due to the highly sensitive nature of blanket bog habitats, this may mean that some restoration proposals will need to optimised within the constraints present on a site-by-site basis to safeguard the sensitive features on those sites.

The information provided in Table 7 sets out the current indicative restoration costs for different types of restoration intervention based on recent MFFP cost experience. These are indicative costs only for restoration works provided at the time of writing and are subject to change over time. The costs are based on the average costs for this type of work in season 2020–21, plus an allowance of 10% for inflation, and do not include project management costs for MFFP.

Table 7. Indicative costs by type of intervention (ex VAT) by type of intervention (capital costs only excluding all revenue-related costs)

Item	Unit	20–21 rate	Estimated Current rate
Brash	Bag (49 sq.m)	68	£75
Lime, seed and fertiliser (LSF) initial aerial application	Hectare	1086	£1,195
Maintenance lime and fertiliser (LF) aerial application	Hectare	733	£806
LSF hand application	Bag (49 sq.m)	18	£20
LF hand application	Bag (49 sq.m)	14.7	£16
Grip/ gully blocking – average	Dam	86.43	£95
Grip/ gully blocking – peat	Dam	27	£30
Grip/ gully blocking – timber	Dam	42.49	£47
Grip/ gully blocking – heather bale	Dam	69.75	£77
Grip/ gully blocking – plastic	Dam	95.3	£105
Grip/ gully blocking – stone	Dam	170	£187
Grip/ gully blocking – coir	Dam	63.5	£70
Re-profiling	Metre	6.5	£7
Bunding	Hectare	815	£897
Cutting for diversity – Molinia	Hectare	1000	£1,100
Cutting for diversity – heather	Hectare	1000	£1,100
Cutting for diversity – cotton grass	Hectare	1000	£1,100
Cutting Molinia – repeat	Hectare	1000	£1,100
Vascular plug plants	Hectare	2750	£3,025
Plug plants – cotton grass	Hectare	1900	£2,090
Plug plants – 50 per bag of brash (10,000 per ha or 1 per sq.m)	Hectare	11000	£12,100
Rhododendron control	Hectare	300	£330
Bracken Control – hand spraying	Hectare	1200	£1,320
Sphagnum plugs – 1250 per hectare	Hectare	720.9	£793
Sphagnum – dense 2500 plugs per ha	Hectare	1515	£1,667
Sphagnum – dense 4000 plugs per ha	Hectare	2560	£2,816
Sphagnum – dense 2000 clumps translocated per ha	Hectare	1480	£1,628
Sphagnum plugs	Per plug	0.63	£1
Fencing	Metre	11.58	£13
Field Gate	1 field gate (3m)	742	£816
Dry stone walling	Metre	32.9	£36
Tree planting	Hectare	8000	£8,800

An example of how these costs have been previously applied to a site has been set out below for a representative site in the Calderdale Council area with a mixture of blanket bog states present on the site and varying wildfire severity risk. As stated previously, the cost identified are indicative only and this illustration does not signify that all the work costed out will be feasible and/or represent all work that could be undertaken. The costs are to be used as a guide and are subject to change.

Looking at past restoration that has been undertaken by MFFP, it is conservatively estimated that the average cost to restore one hectare of blanket bog from a starting State of 2a, 3, 4 or 5 could be circa £10,000, which will start at the blanket bog site on a trajectory of recovery. It could take a significant time for it to achieve the desired state of blanket bog and require further investment over time to maintain the recovery started. Therefore, if we apply this to all relevant blanket bog survey squares in Calderdale (10,156 ha), the total restoration cost could be approximately £101,560,000. However, this figure should be considered simply as a **conceptual** maximum potential amount of investment inferred through a simple extrapolation of the survey area and average cost per ha. This figure is so large as to be limited in its usefulness in practical terms, given realistic funding availability. However, it is useful in an illustrative sense in outlining the scale of the financial challenges if all the blanket bog habitats in the area were to be restored at pace to the fullest scale theoretically applicable.

Table 8 breaks down this maximum total cost by area of land within each Severity Category, using the nominal assumed cost of £10k per hectare to restore blanket bog States 2a, 3, 4 and 5. This very broadly outlines that circa 25% of the costs (at the maximum scale) are likely required to address the areas of high risk, 50% of costs those areas at medium risk and 25% for those areas of lower risk. The identification of this proportionality between risk categories is informative as it can be usefully applied to more practicable cost modelling at the detailed restoration planning stage as a guide to decision-making at scale.

Table 8. Calderdale blanket bog restoration costs by wildfire severity risk category.

Severity Category	Area of study (ha)		Cost (ex VAT) (ha x £10k)
High	2,392		£23,920,000
Med	5,300		£53,000,000
Low	2,464		324,640,000
Total	10,156		£101,560,000

Table 9 identifies the typical restoration interventions that would be commonly undertaken on the different states of blanket bog. It should be noted that just because an intervention is not present (e.g. no re-profiling in State 3) it does not mean that these restoration interventions should not be considered as potentially being required, as dictated by site-specifics. The actual interventions on each site will depend upon the conditions found on site and the objectives and long-term plans for that site.

Table 9. Typical restoration interventions by state of blanket bog.

State 2	State 2a	State 3	State 4	State 5
Brash spreading	Gully blocking (all types)	Heather cutting	Molinia cutting	Sphagnum planting
Initial (LSF)	Plug planting	Plug planting	Follow up Molinia cutting	Bunding
Maintenance LSF	Sphagnum planting	Sphagnum planting	Plug planting	Gully blocking (all types)
Plug planting	Re-profiling	Gully blocking (all types)	Sphagnum planting	
Sphagnum planting		Bunding	Gully blocking (all types)	
Re-profiling gully sides			Bunding	
Gully blocking (all types)				

All restoration interventions are carefully planned and targeted on sites in such a way as to optimise outcomes in the most cost-efficient and timely way. This is inevitably constrained by the availability of funding and, therefore, it is necessary to target interventions in a prioritised and outcomes-focused way. In practice, this means that restoration capital is not evenly applied by area (ha) as per our arbitrary high-level cost scenario outline above. Beyond outlining the scale of the challenges in the Calderdale area, this figure has limited use with respect to practical applications for the next steps in planning for restoration, for the reasons discussed above. To provide further context and apply a practitioner's perspective on likely restoration costs, a site-scale case study is provided below.

7.1.2 Case Study

In order to illustrate the costs associated with a single site, the predicted restoration costs for this site were calculated based upon a completed, detailed site survey (Table 10). The site represents a typical site within Calderdale Council area and covers 701 ha which includes State 3, State 4 and State 5 blanket bog based upon the above assessment. The site also has areas of high and medium wildfire severity risk.

Table 10. Restoration costs associated with the case study site.

Treatment	Number of Units	Total Cost (£ excl. VAT)
Brash (Bags)	390	£27,300.00
Lime, Seed & Fertiliser (total) ha	2.07	£7,596.90
Year 2 Lime and Fertiliser (total) ha	1.92	£5,760.00
Year 3 Lime and Fertiliser (total) ha	1.92	£5,760.00
Re-profiling (m)	2,557	£17,899.00
Dense sphagnum planting (@4000 per ha) (ha)	0.377	£994.07
Standard Sphagnum planting (@1250 per ha) (ha)	328.39	£266,816.88
Sedge/ dwarf shrub Plug plants (@10,000 per ha) (ha)	0.146	£1,814.78
Sedge/ dwarf shrub Plug plants (@2,500 per ha) (ha)	44.58	£126,272.85
Grip/ Gully Blocking: Peat (Dam)	1,050	£29,400.00
Grip/ Gully Blocking: Timber (Dam)	94	£4,136.00
Grip/ Gully Blocking: Heather/coir (Bale/log))	1,248	£119,808.00
Grip/ Gully Blocking: Plastic (Dam)	10	£100.00
Grip/ Gully Blocking: Stone (750 kg)	327	£57,225.00
Surface Bunding (ha)	41.49	£46,053.90
Molinia Cutting (ha)	4.3	£4,429.00
Heather Cutting (ha)	12.84	£13,225.20
Bracken management (ha)	70.87	£85,044.00
Footpath works (m)	54	£10,260.00
Stock fence repair (m)	7	£81.06
Tree Planting (ha)	30.71	£245,680.00
Total		**£1,075,556.13**

Once the relevant permissions and statutory consents had been obtained, it is estimated that it would take up to 3 years to deliver these capital works in the case study, depending upon a number of variables such as contractor availability, weather conditions etc.

7.1.3 Further Context on the likely level of investment required

Extrapolating costs from the site-scale offers a greater insight with respect to likely cost implications for restoration across the whole study area. The site used in the case study is 701 ha in size and can be thought of as a typical example of the wider area, both in terms of blank bog states present on the site and the wildfire severity risk assessed through this study.

701 ha constitutes circa 7% of the total relevant survey area for this study (10,156 ha). By extrapolating the costs from the case study site (£1,075,556) as being likely representative of the practical level of investment needed/ achievable, this identifies a likely funding requirement for capital restoration interventions for the whole survey area of circa **£15.4m** (£1,075,556/ 7(%) x 100 (%) £15,365,085). This again can only offer an illustration of likely costs, but one that is constrained through greater focus on site specifics. Accordingly, this can be regarded as more representative for the purposes of developing future funding strategies for Calderdale. If we then apply the results of the wildfire severity assessment, which identified that 79% of the survey area was at medium or high risk, this would point to a possible restoration funding requirement of circa £12m (£15,365,085 x 79% = £12,138,417) to address the high- and medium-priority areas.

It is recommended that a partnership working approach is taken to develop a funding strategy for peatland restoration for the Calderdale area, using this assessment and prioritisation to form one of the multiple aspects for guiding this activity, in terms of multiple outcomes and approaches to prioritisation.

7.2 Peat depth

Detailed information on peat depths across Calderdale will help to provide a clearer picture of carbon stores held within the peatland areas of Calderdale, in turn, helping to value the protection of those stores and potential threats to the UK achieving its carbon targets under the 25 Year Environment Plan (UK Gov, 2021). Some peat depth data has, and can be gathered through agri-environment schemes, such as the Sustainable Farming Initiative, for individual land holdings. However, anything close to complete coverage for Calderdale is unlikely to become available in the short to medium term without a more cohesive approach.

7.3 Firefighting resources

As mentioned in 5.3, the study did not include an audit of landowner or land manager firefighting equipment or personnel. The ability to respond quickly to fires and effectively control them will affect the outcome and impact of a fire, and an understanding of such resources may provide an additional means of prioritising where wildfire mitigation efforts are focused.

7.4 Community engagement

In order to inform land managers and the general public of the risk of wildfire and the importance of remaining careful and vigilant in protecting this vital habitat, a "Be Fire Aware" campaign (such as the one conducted by MFFP under the MoorLIFE 2020 project) is essential. This could involve a combination of face-to-face engagement (MFFP employed the "Bogtastic van" at public events and high-risk areas) and social media campaigns. These would be stepped up at times of increased fire risk.

7.5 Ignition Risk

As this study focuses on wildfire severity risk, comparing the results to wildfire ignition risk would be useful to help identify areas where community engagement and additional fire fighting resource should be targeted. MFFP have previously undertaken GIS modelling work mapping the ignition risk for wildfires in the PDNP. This work could be rolled out to Calderdale in the future.

8. Conclusions

One of the key threats to blanket bogs is wildfire. Because of this, it is important for those tasked with preventing and fighting wildfires, and with future planning and management, to understand where severe wildfires could take hold and what tools are available if this happened.

Desktop and field surveys shows that 79% (8,740 ha) of the moorlands on deep peat have a medium to high wildfire severity risk, based upon the wildfire severity matrix scoring approach. Furthermore, with climate change potentially making wildfires more severe and more frequent, this could increase the number of medium to high wildfires to 85% (9,356 ha), based on findings from this study. This could impact a number of ecological and societal factors, including air pollution, degradation of water quality, loss of species and habitats and increases in carbon emissions.

As well as surveying for wildfire severity, the state of blanket bog in Calderdale was assessed using the Six States of Blanket Bog by field surveyors. This concluded that State 4 was the most common blanket bog state found in Calderdale with 55% (6,092 ha) identified. The least common state of blanket bog found was State 2 with no occurrences found within the survey area. This is a positive finding from the study, because it indicates there are no large areas of bare peat present and the low surface roughness that confers. Extensive bare peat would increase flood risk downstream of the moorlands and have negative impacts on water quality and carbon loss (as particulate organic carbon and dissolved organic carbon) through erosion.

Using generic values for GHG emissions (see Table 1), this will enable us to estimate that 29,871 tonnes of CO_2e per annum is released currently from the blanket bogs of Calderdale, with States 2–4 acting as a source of GHG emissions, whereas States 5 and 6 are acting as a sink for CO_2e.

Another positive finding is that there were 0.6% (44 ha) of State 6 habitat found within the survey area, which is the target habitat for restoration, because of the improvements to biodiversity and improvements to water quality this state can bring. This is below the 13% (ONS, 2018) of blanket bogs identified as being in a favourable condition by Natural England in 2018. Whilst this is different to the six states of blanket bog it is comparable in state.

Statistical comparison of both datasets detected no statistically significant relationship between the two variables, X^2 value is 271.5 and a "*p*" value of 1.41. However, the lack of a detectable relationship within this project's data cannot be reliably extrapolated to a conclusion that there is no strong relationship between the condition of blanket bog and its risk of severe wildfire (see section 6.3). Despite there not being a statistically significant relationship for all the states of blanket bog, both datasets can be used to identify a priority order in which restoration should be undertaken, which can be found in Table 5.

Indicative restoration costs were also worked out, which suggested that it would cost £101,560,000 to place all the areas surveyed into a secure trajectory towards State 6 blanket bog, with Table 7 suggesting the typical interventions by the different states of blanket bog. Typical restoration costs for a typical site in the Calderdale area were provided as a case study. This gave a figure of £1,075,556 for restoring that site.

Using that site-specific restoration cost figure, the illustration of likely restoration costs was further refined in line with proportional and prioritised restoration, as indicated by the survey results, to a figure of circa £12m to address all medium and high-priority areas.

In achieving the aims of this project, MFFP developed (in-house and through expert consultation) and implemented an innovative method of assessing risk of severe wildfire at the landscape scale. This has facilitated a characterisation of the majority of the peatland areas of Calderdale in terms of their habitat condition and value, and the relative threat posed to them from wildfire. In turn, this has allowed the calculation of an illustrative cost for prioritised restoration aimed at reducing the risk of severe damage from wildfire and increasing habitat resilience in the face of wildfire and climate change. Alongside the outcomes specific to Calderdale, the project complements existing knowledge and understanding surrounding the assessment and mitigation of wildfire risks, and identifies areas where that knowledge could be improved, such as with more detailed information on peat depths.

With the outcomes of this project as a starting point, alongside other activity relevant to prioritising multiple outcomes for Calderdale's upland catchments, a funding strategy to enable more focused, site-specific restoration works planning can be developed. MFFP would be keen to continue a dialogue and discuss approaches to realising peatland restoration recommendations made in this report through partnership working.

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Appendix 1 Wildfire Severity Matrix

Calderdale wildfire severity and access characteristics survey form

Fire severity is the loss of or change in organic matter aboveground and belowground (Keeley, 2009), and includes the indirect impacts such as subsequent soil erosion and flood risk that wildfire can causes.

		Factors	Is the factor present at the survey location? Yes	No	Surveyor comments
Biotic	Plant species (field survey)	Bracken			
		Young trees (0-20 yrs, max 15cm DBH) CONIFER			
		Young trees (0-20 yrs, max 15cm DBH) BROADLEAF			
		Established trees (20 yrs+, min 15cm DBH) CONIFER			
		Established trees (20 yrs+, min 15cm DBH) BROADLEAF			
		Heather *(Culluna vulgaris)*			
		Bilberry/other shrubs			
		Gorse			
		Rhododendron			
		Mosses			
		Grasses/sedges			
	Sward height (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		Bare Peat			
		Ankle			
		Knee			
		Hip			
		Chest+			
	Sward structure (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		Fine fuel only (up to 6mm diameter)			
		Coarse fuel only(6mm+)			
		Fine and coarse fuels below and above 6mm			
	Species uniformity (60%+ 1 species?) (field survey)	Areas of 50-100m only			
		Areas of 100-250m			
		Areas of 250 - 499m			
		Areas of 500m+			
Abiotic	Aspect (desktop survey)	*One option chosen based upon desktop survey*			
		N			
		NE			
		E			
		SE			
		S			
		SW			
		W			
		NW			
	Slope (desktop survey)	*One option chosen based upon desktop research*			
		Level			
		shallow slope			
		steep slope			
	Topography (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		Smooth			
		Undulating/lumpy			
		Gullied			
		Severely gullied			
	Ground moisture (desktop survey)	*One option chosen based upon desktop research*			
		Low			
		Medium			
		High			
	Surface water (desktop survey)	*One option chosen based upon desktop research*			
		No pooled water visible			
		infrequent pooled water (0-15% of ground surface)			
		frequent pooled water (15 - 50% of ground surface)			
		significant pooled water(50%+ of ground surface)			
	Site features which may affect wildfire severity (field survey)	Water course			
		Rocky outcrop			
		Track/road			
		Timber infrastructure (sheds, barns, fences,)			
		Other (please specify)			
	Additional surveyor notes on wildfire severity factors (field survey)				
Access Characteristics	Track surface (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		Hard surface (tarmac, hard-core etc.)			
		Geotextile			
		Unsurfaced mineral soils			
		Unsurfaced peat soils			
	Track width (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		>2.5m			
		<2.5m			
		<2.0m			
	Track Height (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		>3.6m			
		<3.2m			
		<1.9m			
	Slope of track (field survey)	*One option chosen based upon desktop research*			
		≥1 in 20 (~3 degrees)			
		6 - 10 degrees			
		10 - 20 degrees			
		20 + degrees			
	Camber on track (field survey)	*Surveyor to select which of the option below best represents the survey point*			
		≥1 in 20 (~3 degrees)			
		<1 in 20 (~3 degrees)			
		1 in 40 to 1 in 33 (2.5 to 3 %)			
		1 in 33 - 1 in 25 (3 to 4 %)			
	Tight turn (field survey)	Suitable for fire appliance			
		Suitable for 4x4 SUV			
		Suitable for UTVs (e.g. Polaris)			
		Hard obstacle on inside of turn			
	Obstructions	Overhead obstruction present			
		Pedestrian gate present			
		Vehicle gate present			
		Size of gate (if applicable)			Add in a figure
		Track crosses a bridge			
		Max. gross weight (tonnes) (if applicable)			Add in a figure

Appendix 2 Report maps

(Provided as a separate document.)