Peak District National Park

CLIMATE CHANGE VULNERABILITY ASSESSMENT

Contents

1. Executive summary

1.1 Aim

This report assesses how vulnerable the special qualities of the Peak District National Park (PDNP) are to future climate change. The assessment will help to ensure that activities undertaken to reduce the harmful effects of climate change are effectively and efficiently targeted. The report and its recommendations will be useful to everyone interested in caring for and protecting the National Park.

1.2 Background

Climate change is likely to affect the natural beauty, wildlife and cultural heritage of the PDNP. It will also negatively impact many ecosystem services that we benefit from such as food production and water quality. Practical interventions that will help the PDNP adapt to a changing climate need to be developed and prioritised. To do this effectively an understanding of the vulnerability of the PDNP's special qualities to climate change is needed.

The assessment report was produced by collating evidence and knowledge from a broad range of sources and experts. The assessment is the degree to which a feature of a National Park special quality is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. The assessment took into account four factors: the current condition of the feature, the sensitivity of the feature to climate change, the exposure of the feature to climate change and the adaptive capacity of the feature.

1.3 Special qualities and features

The following 'special qualities' define what is distinctive and significant about the PDNP.

- Beautiful views created by contrasting landscapes and dramatic geology.
- Internationally important and locally distinctive wildlife and habitats.
- Undeveloped places of tranquillity and dark night skies within reach of millions.
- Landscapes that tell a story of thousands of years of people, farming and industry.
- Characteristic settlements with strong communities and traditions.
- An inspiring space for escape, adventure, discovery and quiet reflection.
- Vital benefits for millions of people that flow beyond the landscape boundary.

This report assesses a broad selection of the measurable individual 'features' that underpin the PDNP's special qualities. Features are components that make up the special quality, for example, a specific habitat, species or heritage feature such as dry stone walls.

1.4 Assessment results

The special quality most vulnerable to climate change is 'Internationally important and locally distinctive wildlife and habitats'. Changes to rainfall patterns, with wetter winters and drier summers, as well as extremes of drought and flooding are the key factors likely to affect habitats and species in the PDNP. The current poor condition of many features has contributed to them being rated as 'very high' or 'high' in terms of overall vulnerability to climate change.

A number of other special qualities are highly vulnerable to climate change. These are 'Beautiful views created by contrasting landscapes and dramatic geology', 'Undeveloped places of tranquillity and dark night skies within reach of millions', 'Landscapes that tell a story of thousands of years of people, farming and industry', and 'Vital benefits for millions of people that flow beyond the landscape boundary'. The special qualities, ‘Characteristic settlements with strong communities and traditions’ and ‘An inspiring space for escape, adventure, discovery and quiet reflection’ are moderately vulnerable to climate change.

Of the 61 sets of special quality features assessed, 8 have a ‘very high’ vulnerability rating, 36 have a ‘high’ vulnerability rating, 16 have a ‘moderate’ vulnerability rating, and 1 has a ‘low’ vulnerability rating. Ratings are calculated by considering the various direct and indirect effects climate change will have on the feature, the capacity for a feature to adapt to these impacts and the current condition of the feature.

1.5 Recommendations

The vulnerability assessment focuses on identifying and prioritising adaptation measures, which are the physical or behavioural changes needed to help the PDNP adapt to our changing climate. We have not considered climate change mitigation measures, which are those actions that contribute to reducing climate change, as those measures are considered elsewhere.

Recommendations have been made for each of the assessed features to help them become more resilient to the impacts of climate change. The assessment does not seek to prioritise, make commitments to or provide mechanisms for implementing these recommendations. Many of the recommendations will only be implemented if appropriate incentives and, where necessary, changes to the regulatory framework are introduced.

A key overarching recommendation is therefore to seek to influence national land-use policy and ensure local delivery mechanisms are in place in order to contribute to the government’s 25-year Environment Plan, nature recovery networks, and recommendations arising from the 2019 Landscapes Review of National Parks and AONBs.

1.6 Next steps

The vulnerability assessment’s findings will enable the Authority and its partners to direct energy and resources to those climate change adaptations that will have the greatest positive impact on the special qualities.

Due to the broad nature of the vulnerability assessment, implementation of the recommendations will be via a number of mechanisms. It should be noted that although the Authority has commissioned the CCVA, it is for the benefit and use of everyone who wishes to care for and protect the National Park.

As there are a variety of delivery mechanisms it is not envisaged that all the recommendations will be implemented at the same time. Furthermore, in some cases it will be a question of taking opportunities to deliver the recommendations when they present themselves, for example, potential new sources of funding. Inevitably some of the recommendations are contentious. For example, some impact directly on the work of land managers, e.g. recommendations for appropriate grazing levels and suggestions to reduce burning. It will take time to change culture and working practices, so some recommendations will need to be supported by communication and engagement programmes.

Using the evidence base provided by the assessment will be critical in undertaking our future influencing and regulatory roles.

2. Introduction

2.1. Background to the Peak District National Park and Peak District National Park Authority

The Peak District National Park (‘PDNP’) was the first in the UK to be designated (in 1951) for its outstanding landscape, environment and wildlife. Around 20 million people live within an hour’s travel and there are approximately 38,000 residents. Every year millions of people visit to take part in a wide range of activities.

The statutory purposes of the Peak District National Park Authority (‘the Authority’) are to:

1. Conserve and enhance the natural beauty, wildlife and cultural heritage
2. Promote opportunities for the understanding and enjoyment of the special qualities of national parks by the public.

In doing this, the Authority’s duty is to seek to foster the economic and social wellbeing of local communities within the PDNP. We are the planning authority and set the policy framework for development, including for mineral workings. We are the access authority for the purpose~~s~~ of managing public access to the 37% of the PDNP that is open country under the Countryside and Rights of Way Act 2000.

Seven **‘special qualities’** define what is distinctive and significant about the PDNP. The Authority and its partners conserve and enhance these special qualities while promoting opportunities for people to understand and enjoy them.

The seven special qualities are:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- Undeveloped places of tranquillity and dark night skies within reach of millions
- Landscapes that tell a story of thousands of years of people, farming and industry
- Characteristic settlements with strong communities and traditions
- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape boundary.

2.2. Why carry out a climate change vulnerability assessment?

Climate change is a serious long-term threat to the PDNP’s special qualities. It is likely to change the PDNP’s natural beauty, wildlife and cultural heritage and could affect the ecosystem services and other benefits that the PDNP provides.

Practical interventions that will help the landscape, wildlife and cultural heritage to cope better in a changing climate, also known as ‘**adaptation measures**’, need to be developed and prioritised. To do this, an understanding of the ‘**vulnerability**’ of the PDNP’s special qualities to climate change is needed. These ‘adaptation measures’ differ from mitigation measures, which are those actions that contribute to reducing climate change. These mitigation measures are considered elsewhere; for instance, in the National Park Management Plan and the Authority's Carbon Management Plan 2.

This document is an independent, specially commissioned report that has been undertaken on behalf of the PDNPA to assess the vulnerability of a broad selection of the measurable individual ‘**features**’ that underpin the PDNP’s special qualities. It focuses in detail on the features most vulnerable to climate change. Together, these assessments provide a good indication of the overall vulnerability of the special qualities as well as providing a detailed overview of the vulnerability of individual features. This report also fulfils the PDNPA’s commitments to undertake a climate change vulnerability assessment as set out in the 2016 Climate Change Adaptation Report and the 2018-23 National Park Management Plan.

2.3. How will the vulnerability assessment be used?

This is a critical piece of evidence that will inform future PDNP Management Plans, the Peak District Local Plan, the Peak District Landscape Strategy and the Authority's Corporate Strategy. It will guide the development of policies and actions that will help ensure the PDNP's special qualities adapt to climate change and are looked after now and for future generations. This report's findings will enable the Authority and its partners to best direct energy and resources to those climate change adaptations that will have the greatest positive impact on the special qualities.

2.4. How to use this report

We have presented the findings of this assessment in two ways: by special quality and by theme.

The special qualities section gives a broad overview of the results of the vulnerability assessments, aggregated into the seven special qualities. It is useful for those interested in the vulnerability of the special qualities to climate change or those seeking a broad overview of the assessment results.

In contrast, the themes section includes the full set of feature-level vulnerability assessments, which we organised into themes to aid interpretation and comprehension. This is useful for those interested in the detail of the assessments or in the vulnerability assessments for individual features.

The vulnerability assessments can also be interpreted geographically by national character area using the maps in each of the feature assessment pages.

2.5 Recommendations for adaptation

The key recommendations for adaptation arising from this assessment are presented with each feature in the main body of this document. In addition, the recommendations have been grouped by the special qualities to which they are relevant. These are listed in appendix 5. This appendix contains the same information as the main feature recommendations, simply organised in a different way to assist users mainly interested in special qualities.

The recommendations made in this report represent *possible* actions requiring future consideration, for example by the National Park Management Plan Steering Group. It should be noted that these recommendations are made solely with adaptation to climate change in mind. This report is not an assessment of the feasibility or impact of these recommendations on factors not related to climate change. They do not represent commitments made by the PDNPA or its partners. It is important to recognise that many of the recommendations made can only happen if there are appropriate incentives and, where necessary, a regulatory framework in place to make them a viable option for land managers.

3. Methodology and background assumptions

3.1. Future climate scenarios

In order to assess vulnerability to climate change, we used future climate scenarios to look at predicted climate change impacts based on projected future changes in human greenhouse gas emissions. The scenarios we used are two of the Representative Concentration Pathways (RCPs) from the most recent UK Climate Projections 2018 (UKCP18):

- RCP 4.5, which assumes that emissions peak in approximately 2040 before slowly declining
- RCP 8.5, which assumes that emissions continue to rise throughout the century.

We used the probabilistic projections for the six 25km grid squares that cover the PDNP.

Both scenarios are consistent in their broad projected trends, which are for hotter, drier summers and warmer, wetter winters. However, the further into the future we look, the greater the divergence between the scenario forecasts and the lower the certainty of these projections. We remained mindful of this throughout the assessment process when forecasting into the future.

We also used headline figures from UKCP18 to make assumptions that extreme weather events – heat, drought, rainfall and coastal water events – will become more frequent and severe and that average sea levels will rise.

More information on this can be found in Appendix 1.

3.2. Vulnerability

To assess the overall vulnerability of the features, we assessed four factors:

- the **current condition** of the feature
- the **sensitivity** of the feature to climate change
- the **exposure** of the feature to climate change
- the **adaptive capacity** of the feature.

These are drawn from the widely accepted definition of vulnerability, set out by the Intergovernmental Panel on Climate Change (IPCC). Figure 1 shows how these four factors combine to create vulnerability.

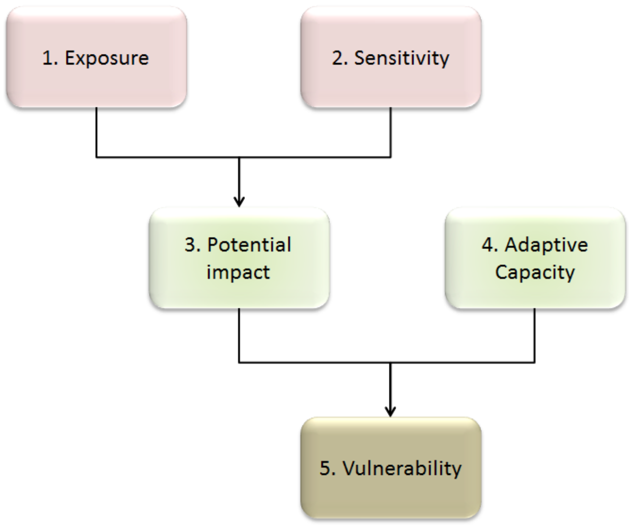


Figure 1.Diagram showing components of vulnerability (after Glick, et al., 2011)

For a more detailed description of vulnerability, see appendix 2.

3.3. Thresholds

We know that climate change impacts will occur both continuously and as step changes when critical thresholds are reached. However, we were unable to identify specific thresholds for change and link them to specific dates, locations or RCP scenarios due to the wide scope of this assessment, the variations of future projections and incomplete knowledge on most of the features being assessed.

Instead, we consulted pre-existing climate change impact models and asked a panel of internal and external specialists to comment on likely general trajectories of change into the remainder of the century, and we only predicted step-changes where possible.

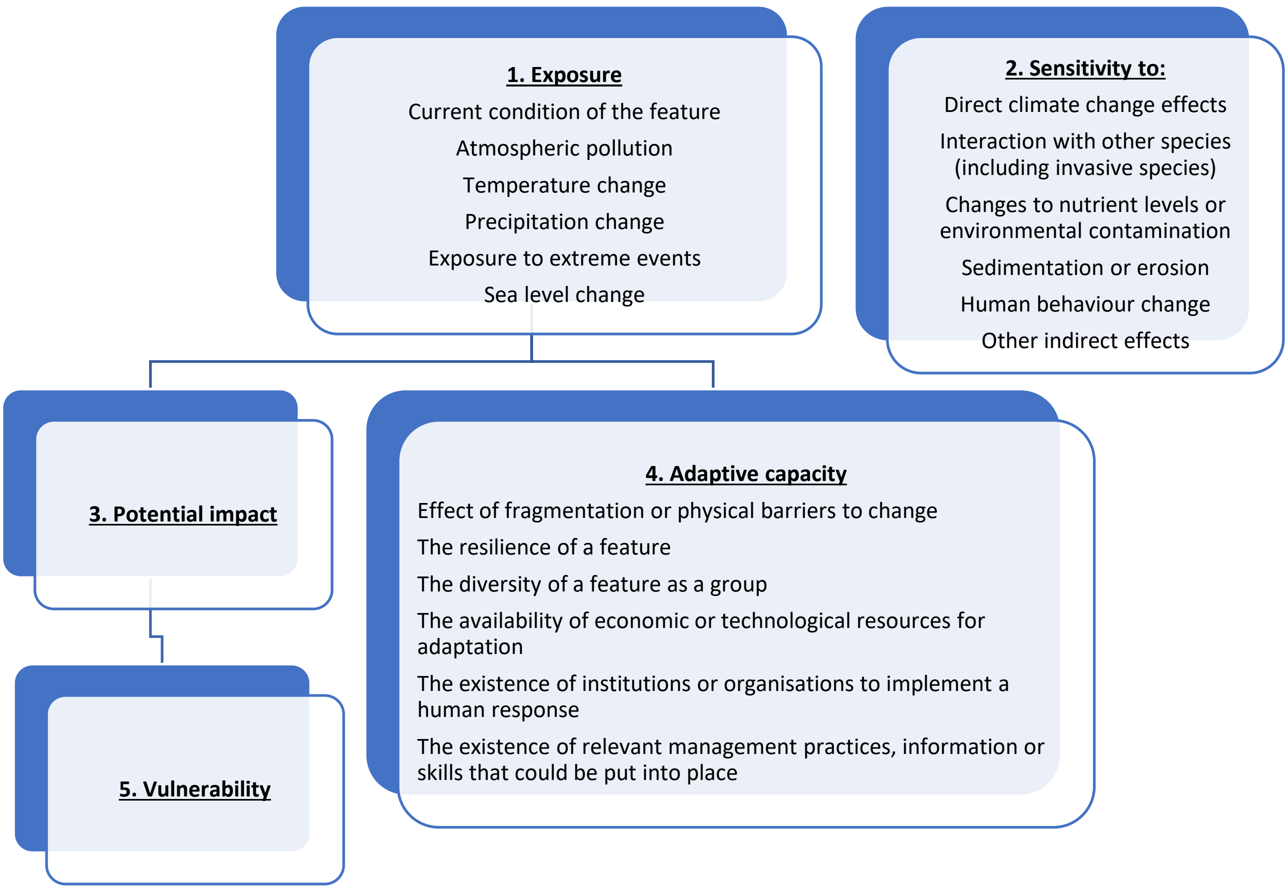
3.4. Certainty and likelihood

The vulnerability assessment looked at the certainty of impacts that may potentially occur. Certainty in this context differs from likelihood and reflects our confidence that a particular impact could exist. So, certainty here is a measure of the strength and consensus of the research on which an assumption about a potential impact is based. Likelihood, in the context of this report, is the chance that a potential impact would take place and it is often difficult to determine. Therefore, we took a precautionary approach and, while we still considered impacts that were seen as less likely, the likelihood itself did not affect the rating.

3.5. Vulnerability assessment approach

In order to measure overall vulnerability for all features in the most robust way possible, we took a semi-quantitative approach based on the Climate Change Vulnerability Assessment Tool for Coastal Habitats system developed by Plunket *et al* in 2015. This is a system of scoring for current condition, sensitivity-exposure (i.e. potential impact), adaptive capacity and certainty. It breaks down sensitivity, exposure and adaptive capacity into sub-categories that can be scored individually, ensuring that all features assessed are treated in a consistent and comparable way. This allowed us to compare the disparate PDNP features, which include both living and non-living features.

Figure 2 illustrates the sub-categories used with our assessment. The definitions and descriptions of these categories and the scoring used can be found as in appendix 3.



4. How vulnerable are the PDNP's special qualities?

4.1. Special quality features assessment approach

The PDNP's special qualities are broad statements that together capture and communicate the essence of what is special about the PDNP. To assess their current condition and vulnerability to climate change, we had to assess the features that make up each special quality rather than the special quality statement itself.

To enable monitoring, each special quality had already been broken down into groups of tangible features that together make up the building blocks of the special quality. For instance, 'Beautiful views created by contrasting landscapes and dramatic geology' has 100 tangible features that can be measured, such as gorges, reservoir valleys and moorland hills. These tangible features are grouped into four categories: 'beautiful views', 'distinctive geology', 'views across contrasting landscapes' and 'landscapes of harmony and detail'.

Due to the large number of features (over 530 in total), we carried out the vulnerability assessment on the highest priority features in order to focus efforts and allow recommendations that deliver the greatest impact. We determined priority with expert consultation using a ranking system that took into account available data, current condition, ability to influence future condition and priority in relation to climate change. To ensure no duplication of effort, we grouped similar features and assessed them together to simplify the assessment process. We removed those features that we could not assess at this time. Following this, 156 features remained (approximately 30% of the total number of special quality features) in 62 feature groups. These are the features that we assessed within this vulnerability assessment.

4.2. Beautiful views created by contrasting landscapes and dramatic geology

Description of special quality

This special quality encompasses the stunning views afforded by the PDNP landscape. Particular reference is given to the contrasting nature of PDNP landscapes, with the high moorland edges of the Dark and South West Peak contrasting with the lower limestone dales and valleys of the White Peak. As well as contrasting landscapes and dramatic geology, characteristic PDNP views are also considered, such as estate lands, blanket bog and meadows.

Features in this category: Boundaries and patterns of enclosure, *Estate lands and designed landscapes, Lowland pastoral landscapes, High open moorland and edges, Limestone dales, River valleys, Slopes and valleys with woodland, Blanket bog, Heather moorland and mixed heath, Limestone grassland, Meadows, Wet grassland and rush pasture, Woodlands, Riverside meadows associated with meandering river channels, Vanishing rivers*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is highly vulnerable to climate change. Of the 15 special quality features assessed, 13% have been rated as ‘very high’ on our scale and 73% were rated as ‘high’. The rest have been rated as ‘moderate’, and no features were given a ‘low’ rating. Extremes of drought or flooding, along with storm damage, are some of the key factors likely to affect beautiful views in the PDNP.

Additionally, poor or variable current condition has contributed to many features being rated as ‘very high’ or ‘high’ in terms of overall vulnerability to climate change. Current condition is usually due to non-climate factors. For many features, a low diversity of plant species and widespread habitat fragmentation have contributed to this vulnerability. Meadows, hedgerows, and woodlands are all prime examples. Bare peat and limestone have high levels of erosion risk that may be accelerated with changing rainfall patterns. Rivers and their riparian habitats are also vulnerable to changes in rainfall intensity.

Many habitats and cultural landscapes in the PDNP are threatened by human responses to climate change, such as land use changes and higher visitor numbers. Pathogens and pests that are predicted to spread more rapidly in warmer, wetter climates may further damage stressed plants and animals, altering landscape aesthetics.

Current condition, vulnerability and adaptive capacity of features

Estate lands and designed landscapes – High vulnerability Estate lands and designed landscapes in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and moderate adaptive capacity. Many estate lands are well managed and have ongoing maintenance and development plans. The current condition for those held in private ownership is more difficult to determine. Extreme events including heavy rainfall and flooding, but particularly drought, could have a significant impact on estate lands and designed landscapes. There is capacity for adaptation as most have a management plan or similar system in place. Some estates are also given protection through their registered status. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Lowland pastoral landscapes – High vulnerability** Lowland pastoral landscapes in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a vulnerable current condition and moderate adaptive capacity. Lowland pastoral landscapes in the PNDP are vulnerable to changes in economic and political conditions, with agricultural intensification already affecting the historical character of many farms. One of the key potential impacts of climate change is a change in land use, particularly a turn to more arable usage with fields ploughed and remaining flower rich grasslands lost. Many small dairy farms have already been lost and been replaced by larger holdings with an increased demand for larger building and fields, together with fewer meadows and more fodder crops. However, sustainable and sensitive farming techniques could be implemented more widely to help offset some climate change impacts. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Slopes and valleys with woodland – High vulnerability Slopes and valleys with woodland in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable condition and a moderate adaptive capacity. Wooded slopes and valleys in the PDNP are already in a poor state, with low diversity and invasive species in many areas, and replacement by conifer plantations affecting others. An increased prevalence in extreme events, rainfall and higher temperatures would have a large negative impact on the woodland significantly affecting the feature. The feature may be damaged directly or indirectly by invasive species, nutrient changes and human	**High open moorland and edges – High vulnerability** High open moorland and edges in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a moderate adaptive capacity. High open moorland and edges in the PDNP are in generally poor condition, with blanket bog in the worst state ecologically and hydrologically. They are particularly sensitive to hotter, drier summers and the resulting wildfire and erosion potential. Moorland edges also often have a high heritage significance, and surface and buried archaeological features are very sensitive to factors such as changes in vegetation, soil erosion and wildfire.

behaviour change resulting from climate change. Slopes and valleys with woodland are somewhat resilient as there are funds available through environmental stewardship options and other national schemes for maintenance, restoration and tree planting. However significant intervention will be required in order to make this feature resilient to climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	High open moorland and edges have a moderate adaptive capacity, but realising this is reliant on economic subsidy and management regime agreement in the long term, unless radical changes to the landscape are allowed to take place. The adaptive capacity of archaeological sites is lower once they have reached the point of being exposed through soil erosion or wildfire for example. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Limestone Dales – High vulnerability Limestone dales in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity. The condition of limestone dales in the PDNP is generally good but subject to some pressures. Changes to water levels could have a major impact on habitat and how the land is used in the future. This will affect the appearance and appeal of the landscape. Damage to parts of this feature will be irreversible, reducing its adaptive capacity, however there are schemes which could help with adaptation and a large proportion of the sites are formally protected. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**River Valleys – Moderate vulnerability** River valleys in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, but with a high adaptive capacity. River valleys in the PDNP are generally in functional condition, though as active hydrological systems changes are fast. An increase in rainfall intensity and flooding is the key potential impact of climate change in river valleys. However, natural flood management schemes are part of the Department for Environment, Food and Rural Affairs (DEFRA’s) 25-year plan and there are multiple management strategies that could be implemented to increase significantly the adaptive capacity of river valleys. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**
Limestone grassland – Moderate vulnerability Limestone grassland in the PDNP has been rated ‘moderate’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but also a high adaptive capacity. Limestone grassland in the PDNP has a limited extent, but much of what remains is protected by Site of Special Scientific Interest (SSSI) designation. Overall habitat persistence is likely to be determined by non-climate or indirect human factors, for example changes in agricultural economics, with areas such as the	**Blanket bog – Very high vulnerability** Blanket bog and associated features in the PDNP have been rated ‘very high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor ‘non-functional’ current condition, and a low adaptive capacity. Historically in an extremely degraded condition, many areas are recovering under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations and through

dales likely to be impacted. The iconic Jacob's-ladder grassland may be particularly vulnerable and in need of conservation actions. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	landscape scale conservation works. Areas undergoing conservation works are likely to be less vulnerable than those which are not; and modelling suggests that the lower altitude bogs on the eastern edge of the Dark Peak may be among the most vulnerable areas, whilst the more continuous and higher altitude areas in the north of the PDNP may be less vulnerable. The area and quality of active blanket bog in the PDNP may be reduced by climate change. **Overall impact rating: HIGH** **Overall adaptive capacity rating: LOW**
Heather moorland and mixed heath – High vulnerability Heather moorland and mixed heath in the Peak District National Park has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively poor but recovering current condition, and a moderate adaptive capacity. Current heath condition in the PDNP is generally poor due to historical stressors and poor management. Modelling suggests that areas such as Eyam Moor and heathland around Chatsworth (for example Brampton East Moor) are likely to be some of the most vulnerable to climate change due to their south-easterly location and lower altitude. Changes in human behaviour may have an important impact on this managed environment. Less biodiverse areas are likely to have the lowest adaptive capacity, meaning moorland with high heather dominance is at risk from climate change. Heathland does however have the advantage of economic and organisational resources dedicated to its conservation, and has high connectivity across large areas. Large areas are protected under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations. In the future, PDNP moorlands are likely to become important habitat for species that currently have a more southerly distribution, such as the Dartford warbler. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Boundaries and patterns of enclosure – High vulnerability** Boundaries and patterns of enclosure have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an often poor general condition, and a moderate adaptive capacity. It is difficult to ascertain the overall current condition of dry stone walls as it is varied. However the condition of hedgerows is viewed as poor. Extreme weather is one of the key potential impacts increasing deterioration and maintenance costs leading to a greater risk of abandonment. Another is changes to land use, which may mean boundaries are removed to enlarge fields. Changing farming practices such as an increase in ploughing may affect earthwork features. Walls in poor condition are also often used as a source of stone to repair other walls. There is limited funding available to improve these features and there is currently a shortage in terms of the number of people with the necessary dry stone walling skills needed for management and maintenance. Even the repair and rebuilding of walls, whilst retaining the landscape appearance, can remove or alter historic information that is very valuable (such as the physical relationships between features, or distinctive construction styles). Planting could improve hedgerows condition by filling in

	gaps and diversifying species. If not designated, prehistoric field systems are vulnerable to landscape change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Meadows – High vulnerability Meadows and associated features in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a varied current condition and highly fragmented habitats, but with a moderate adaptive capacity. Meadows are already in a poor state in the PDNP, with only a few small patches with very limited connectivity remaining. Climate change impacts are unavoidable; key plants and their associated species may be lost. Some meadow species will be unable to thrive with changes in weather, leading to habitat change. Agricultural intensification caused by pressure to grow more food may lead to further habitat loss. A mismatch between flowering and pollination timings may lead to a decrease in some plants. Pollution may cause changes to soil composition. Hay-making may become difficult due to unpredictable weather. Overall, climate change stressors are likely to lead a loss of habitat and biodiversity. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Wet grassland and rush pasture – High vulnerability** Wet grassland and rush pasture in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, the fragmented nature of the more rare and biodiverse rush-pasture type habitats, coupled with a moderate adaptive capacity. Mismanagement and drainage has resulted in many areas of wet grassland becoming species poor, some being dominated by purple moor-grass. The reliance of these grasslands on water input coupled with the economically uncertain nature of upland farming mean that climate changes have the potential for large direct and indirect impacts. However, through environmentally sensitive management and restoration of water tables it should be possible to partially offset some of these impacts. The key adaptation measures are to join up and enhance remaining fragments of rush pasture where it is possible to maintain or increase water levels; and to accept that some areas may need to be converted to other habitat types such as flower rich meadows. The diversification of the sward in purple moor-grass dominated blanket bogs through the reintroduction of *Sphagnum* mosses should increase the biodiversity and the future resilience of these wetlands. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Woodlands – High vulnerability Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented	**Riverside meadows associated with meandering river channels – Very high vulnerability** Riverside meadows associated with meandering river channels in the PDNP have been rated 'very high' on our vulnerability

current condition, and a moderate adaptive capacity. Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under Site of Special Scientific Interest (SSSI) protection faring better. Smaller woodlands with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition and a low adaptive capacity. The extent of riverside meadows has been reduced over the last century with the ecological quality affected at many sites. Extreme weather conditions leading both to flooding and drought could have a significant impact on this feature. The adaptive capacity of river meadows is limited and there is no central organisation with responsibility for their condition. Although the PDNPA can make recommendations as to their management, it has limited power to see that it happens. **Overall potential impact rating: High** **Overall adaptive capacity rating: Low**
Vanishing rivers – High vulnerability Vanishing rivers in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with an unclear current condition, and a moderate adaptive capacity. The greatest impact on vanishing river systems will be changes in rainfall across the year. Greater extremes in precipitation will leave rivers dry for longer and in higher flow when active on the surface. Vanishing rivers have some capacity for adaptation, as their characteristic community is relatively hardy and there are some financial resources available which could increase their adaptive capacity. **Overall potential impact rating: High** **Overall adaptive capacity rating: Moderate**	

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Drier summers	Increased periods of drought	• Visual changes may be prominent in meadows, pastoral landscapes, designed landscapes, and moorland as areas become dry and brown or flowering periods are altered • Changes to vegetation communities as drought sensitive species are lost • Vegetation in some areas of large estates will be stunted, or die off • Reduced plant diversity could reduce the ability of meadows to support populations of invertebrates and seed feeding birds • Erosion rates of peat are likely to increase leading to an increase in gullying, new areas of bare peat and the loss of peat from blanket bogs • Rivers may have reduced water levels or become completely empty • Vanishing rivers could be dry for longer periods of the year, reducing the annual contrast in views
Combined effects	Land use change	• Farming economics may bring about shifts in stocking levels and management techniques which could change the landscape character and lead to the loss of diverse and contrasting views and loss of upstanding remains of heritage assets • Dark and South West Peak moorland may be damaged by fluctuating stocking levels, with possible increases in heather dominance or conversion to acid grassland or bracken domination • White Peak pastureland is at risk, with pressure for suitable land year round possibly affecting traditionally lightly grazed land such as meadows, parkland and dales, and upstanding remains of heritage assets • Construction for livestock shelter and water tanks may become more common • Livestock kept indoors could change the appearance of pastureland, as fields may be empty more often
	Increased threat from pathogens and pests	• Plant diseases such as box blight and ash dieback may become more prevalent, placing the long-term health and diversity of some habitats at risk

		• Landscape aesthetics may be altered as trees and hedges are lost or damaged • Animal pests such as heather beetle may become more prevalent, affecting Dark and South West Peak moorland • On pastoral land, livestock parasites such as liver fluke may become more common
	Climate change adaptation and mitigation efforts increase	• Increased pressure for the introduction of renewable energy sources such as solar farms • Visual impact of solar farms could affect visitor experience of beautiful views • Woodland planting in cloughs and steep valleys may be used to increase carbon sequestration and to aid flood management • Moorland restoration efforts in the uplands of the Dark Peak and South West Peak may be in higher demand to reduce flood risk downstream • Woodland planting and moorland restoration could both alter the view of a natural landscape, and will likely increase wildlife populations
Increased storm events	Intense rainfall, strong winds, and flooding	• In the White Peak, dales could be affected by flash flooding • Flooding may mean river valleys become more inaccessible for visitors or become visually less appealing • Riverside habitats such as meadows will also be at risk of erosion and flooding • Views of vanishing rivers may be altered, as the contrast between the dry riverbed and flowing river becomes more apparent • Rockfalls in the limestone dales may prove a public safety risk and prevent access to some areas, meaning visitors may be less able to experience the views over dramatic limestone geology • In the Dark and South West Peak, storm erosion is likely to increase gullying and degradation of moorland • Moorlands may return to their heavily gullied and bare state, reducing the visual pleasure of variable landscapes with abundant wildlife • In the White Peak, exposed limestone is at risk of weathering more rapidly

		• Limestone landforms may become less appealing as features are worn away or rocks dislodged

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.3. Internationally important and locally distinctive wildlife and habitats

Description of special quality

This special quality encompasses the varied ecology of the PDNP, including individual species as well as the habitats they require. The PDNP contains many habitats, from nutrient poor acid grassland and blanket bog to species rich meadows and limestone grassland. Many rare bird species can be found in these habitats, including the characteristic moorland wader assemblage. Human landscapes are also an important feature for wildlife, including heather moorland and lead mining remains. As the southern edge of the Pennines, the PDNP is a refuge for many upland species that cannot be found further southeast.

Features in this category: *Lead mining, Acid grassland, Blanket bog, Heather moorland and mixed heath, Limestone grassland, Meadows, Wet grassland and rush pasture, Wet heath, Wet woodland, Woodlands, Dewponds and other ponds, Reservoirs, Rivers and streams, Adder, Aquatic invertebrates, Bilberry bumblebee, Curlew, Dipper, Dunlin, Golden plover, Great crested newt, Lapwing, Merlin, Mountain hare, Pied flycatcher, Ring ouzel, Short-eared owl, Snipe, Swallow, Twite, Waxcap fungi*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is the most vulnerable special quality to climate change. This is because 23% of the 31 features assessed have been rated as 'very high' on our scale and almost 70% were rated as 'high'. The rest have been rated as 'moderate', and no features were given a 'low' rating. Changes to rainfall patterns, with wetter winters and drier summers as well as extremes of drought or flooding, are some of the key factors likely to affect habitats and species in the PDNP.

Additionally, poor current condition has contributed to many features being rated as 'very high' or 'high' in terms of overall vulnerability to climate change. Current condition is usually due to non-climate factors. In the case of habitats, poor current condition is often because only small fragments remain – as in the case of meadows and wet woodlands. Interconnection between habitats is also often poor, making them less resilient to change. Past and current human actions such as agricultural improvement of grassland, the switch from hay to silage, and the drainage of wet areas have also contributed to this high vulnerability. Quality of the remaining patches of habitat is also important. For instance, the extremely degraded condition of blanket bog in the PDNP makes it vulnerable despite there being large continuous areas present.

The PDNP is home to a range of species adapted to cooler upland or northerly conditions. Many are on the southern edge of their range in the UK and are unlikely to cope with projected climatic changes, including merlin, twite and the bilberry bumblebee. Modelling shows some may be lost from the PDNP entirely. In addition, human responses to climate change, particularly through changes to agricultural practices, could have profound effects on some species.

Current condition, vulnerability and adaptive capacity of features

Lead mining features – High vulnerability Lead mining in the PDNP has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a highly variable current condition, and moderate adaptive capacity. Lead mining remains in the PDNP are in variable condition, some high value sites are in very good condition, but many other hillocks and sites of ecological interest have been degraded. Changes in the climate could have a major direct impact on these sites altering the composition of the important calaminarian grassland habitats, while increased storm events could lead to pollution further downstream and damage to remaining archaeological features. Spoil tips and workings often comprise loose soils and deposits that are very vulnerable to erosion by wind water and abrasion. Surface features are particularly vulnerable to agricultural improvement, such as infilling and levelling. While some calaminarian grassland species have capacity to adapt, sites are fragmented and recovery from damaging events may be slow. Archaeological features have less adaptive capacity and should be considered a non-replaceable resource. Factors which may help to partially offset climate stressors include the good diversity of archaeological features which still exist, the diverse micro-topography of the remaining lead landscape, and the relatively well-studied nature of assets in the PDNP. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Wet grassland and rush pasture – High vulnerability** Wet grassland and rush pasture in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, the fragmented nature of the more rare and biodiverse rush-pasture type habitats, coupled with a moderate adaptive capacity. Mismanagement and drainage has resulted in many areas of wet grassland becoming species poor, some being dominated by purple moor-grass. The reliance of these grasslands on water input coupled with the economically uncertain nature of upland farming mean that climate changes have the potential for large direct and indirect impacts. However, through environmentally sensitive management and restoration of water tables it should be possible to partially offset some of these impacts. The key adaptation measures are to join up and enhance remaining fragments of rush pasture where it is possible to maintain or increase water levels; and to accept that some areas may need to be converted to other habitat types such as flower rich meadows. The diversification of the sward in purple moor-grass dominated blanket bogs through the reintroduction of Sphagnum mosses should increase the biodiversity and the future resilience of these wetlands. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Blanket bog – Very high vulnerability Blanket bog and associated features in the PDNP have been rated ‘very high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor ‘non-functional’ current condition, and a low adaptive capacity. Historically in an extremely degraded condition, many areas are recovering under Site of Special	**Heather moorland and mixed heath – High vulnerability** Heather moorland and mixed heath in the Peak District National Park has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively poor but recovering current condition, and a moderate adaptive capacity.

Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations and through landscape scale conservation works. Areas undergoing conservation works are likely to be less vulnerable than those which are not; and modelling suggests that the lower altitude bogs on the eastern edge of the Dark Peak may be among the most vulnerable areas, whilst the more continuous and higher altitude areas in the north of the PDNP may be less vulnerable. The area and quality of active blanket bog in the PDNP may be reduced by climate change. **Overall impact rating: HIGH** **Adaptive capacity: LOW**	Current heath condition in the PDNP is generally poor due to historical stressors and poor management. Modelling suggests that areas such as Eyam Moor and heathland around Chatsworth (for example Brampton East Moor) are likely to be some of the most vulnerable to climate change due to their south-easterly location and lower altitude. Changes in human behaviour may have an important impact on this managed environment. Less biodiverse areas are likely to have the lowest adaptive capacity, meaning moorland with high heather dominance is at risk from climate change. Heathland does however have the advantage of economic and organisational resources dedicated to its conservation, and has high connectivity across large areas. Large areas are protected under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations. In the future, PDNP moorlands are likely to become important habitat for species that currently have a more southerly distribution, such as the Dartford warbler. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Limestone grassland – Moderate vulnerability Limestone grassland in the PDNP has been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but also a high adaptive capacity. Limestone grassland in the PDNP has a limited extent, but much of what remains is protected by Site of Special Scientific Interest (SSSI) designation. Overall habitat persistence is likely to be determined by non-climate or indirect human factors, for example changes in agricultural economics, with areas such as the dales likely to be impacted. The iconic Jacob's-ladder grassland may be particularly vulnerable and in need of conservation actions. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	**Meadows – High vulnerability** Meadows and associated features in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a varied current condition and highly fragmented habitats, but with a moderate adaptive capacity. Meadows are already in a poor state in the PDNP, with only a few small patches with very limited connectivity remaining. Climate change impacts are unavoidable; key plants and their associated species may be lost. Some meadow species will be unable to thrive with changes in weather, leading to habitat change. Agricultural intensification caused by pressure to grow more food may lead to further habitat loss. A mismatch between flowering and pollination timings may lead to a decrease in some plants. Pollution may cause changes to soil composition. Hay-making may become difficult due to unpredictable weather. Overall, climate change stressors are likely to lead a loss of habitat and biodiversity. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Acid grassland – Moderate vulnerability	Wet heath – High vulnerability
Acid grassland in the PDNP has been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition and a high adaptive capacity. The condition of acid grassland is variable, with some Site of Special Scientific Interest (SSSI) sites containing areas of high conservation value, but much acid grassland outside of SSSI designation in an unknown condition. The main impact on acid grassland will likely be a change in species composition in response to various climate change effects, either directly or in response to agricultural uses of these habitats. Livestock are a management tool for acid grassland which provide the opportunity for intervention to help this habitat to adapt to the changing climate. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	Wet heath in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with poorly documented current condition, and moderate adaptive capacity. As wet heath depends on waterlogged soils, drying out of some sites represents the greatest risk, with potential reduction of Sphagnum cover adding to the problem. Despite being fragmented, wet heath grades into similar habitat types and so has reasonable connectivity. Organisational and financial support for moorland rewetting will benefit wet heath and counter some of the effects of climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Wet woodland – High vulnerability Wet woodland in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor, highly fragmented current condition, and a moderate adaptive capacity. Wet woodlands in the PDNP are already highly fragmented, but many of the remaining patches are in good condition. Wet woodlands with low tree species diversity are likely to more vulnerable than those that are more diverse. The area of wet woodland in the PDNP may be reduced by climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Woodlands – High vulnerability** Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented current condition, and a moderate adaptive capacity. Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under Site of Special Scientific Interest (SSSI) protection faring better. Smaller woodlands with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Dew ponds and other ponds – Very high vulnerability Dew ponds and other ponds in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor current condition, and a low adaptive capacity.	**Reservoirs – High vulnerability** Reservoirs in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate current condition, and a moderate adaptive capacity.

Extreme events including flood and drought could have a significant impact on this feature, reducing their functionality and potentially leading to ponds being abandoned or infilled. Dew ponds with intact historic surfaces (clay and cobbles) are becoming increasingly rare. The adaptive capacity of this feature is low as there are a limited number that are functional. PDNPA funding is currently available for pond restoration, but this is very limited. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**	Land management practices, human behaviour, and invasive species currently affect the water quality in reservoirs and the species that live in and around them. Reservoir water levels, flow rates and quality may be compromised by climate stressors influencing sites at the catchment level. Habitat for wildlife in and around the reservoirs is likely to change. Reservoirs naturally fluctuate with weather events giving them good ability to recover. However a decline in reservoir water quality continues to pose the biggest threat to people and wildlife that rely on it. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Rivers and streams – High vulnerability Rivers and streams in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a reasonable current condition, and a moderate adaptive capacity. Most major rivers and streams are in a relatively good condition, with localised contamination and invasive species issues. The greatest effects on watercourses are likely to be from changes in precipitation cycles. Watercourses will become more variable, with higher flow in winter and lower flow in summer. Freshwater plant and animal communities are likely to be altered by these changes. Higher temperatures are also likely to affect freshwater communities, with suitable climate space moving northwards and upstream, and warmer conditions causing changes in water chemistry. Rivers and streams are relatively adaptable, with freshwater species having developed dispersal techniques and the watercourses having diverse forms. Much legislation exists to protect and improve rivers and streams, and some funding is available for water quality and flood management works, which will improve river and stream resilience. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Adders – High vulnerability** Adders in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor and fragmented current condition, and a moderate adaptive capacity. The PDNP adder population currently appears to be relatively stable despite its reduced and fragmented nature. Small adder populations are likely to be more vulnerable than larger, more stable populations. Adders have some scope for adapting to climate change, particularly if habitat management is continually improved. Translocation to new sites may also be an option for securing a larger population range within the PDNP. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Aquatic invertebrates – High vulnerability Aquatic invertebrates in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables and a poor current condition, but with a moderate adaptive capacity.	**Bilberry bumblebees – High vulnerability** Bilberry bumblebees in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an unclear but likely poor

Aquatic invertebrate populations in the PDNP likely mirror the national decline, with many species threatened by pollution and invasive species. As aquatic organisms, these invertebrates depend on good water quality, and so they are most sensitive to climate change effects that reduce water quality such as increased siltation and pollution. Changes in annual water cycles, such as altered flow rates and drying out of some habitat, are also likely to have a significant effect. Aquatic invertebrates have a moderate adaptive capacity due to their high diversity and dispersal, and may benefit from economic and institutional efforts to improve water quality. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	current condition, and a moderate adaptive capacity. Habitat changes and a loss of key flowering plants are the biggest threats to this species. Bilberry bumblebees have some scope for adapting to climate change, especially if habitat management focuses on improving floral diversity during nest-building season. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Curlews – Very high vulnerability Curlews in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a low adaptive capacity – despite the currently moderately positive trends in the PDNP compared to the national picture. Curlew populations in the PDNP are reduced from their historical numbers, but recent data suggests they may be recovering. Climate change is likely to have the greatest impact on curlews in their wintering grounds outside the PDNP through sea level rise and flood defence construction. Within the PDNP, effects on soil invertebrate populations are expected to have the greatest impact. As long-lived and site faithful birds, curlew are not very adaptable. Modelling shows curlew moving north and west out of the PDNP by the end of the century, if they still survive locally. Support from organisations and schemes operating in the PDNP go some way to support their conservation, but more could be done. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**	**Dipper – High vulnerability** Dipper in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor but potentially recovering current condition, and a moderate adaptive capacity. The population size in the PDNP is not well known, but national trends show a decline in dipper populations. The largest climate change impacts on dipper will be those that affect their invertebrate prey. Increased water acidity and excess nitrogen will therefore be likely to have the greatest effect. Changes to annual flow cycles will likely also have an impact on dipper populations. The dipper itself is only moderately adaptable, having specific habitat requirements and low dispersal, but could benefit from economic and institutional support. This will mostly be indirect, through initiatives to improve water quality and natural flood management. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Dunlin – Very high vulnerability Dunlin in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a moderately unfavourable current condition and a low adaptive capacity.	**Golden plover – High vulnerability** Golden plover in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity.

Dunlin populations in the PDNP have been in decline historically, but recent increases in some areas are a positive sign for the population as a whole. Dunlin are a relatively mobile species, and rising temperatures are likely to cause breeding populations to move northwards and be lost from the PDNP. Further loss of blanket bog functionality may also disadvantage dunlin populations due to reductions in their invertebrate prey. Blanket bog restoration has proven very beneficial for dunlin, but is may not be enough to retain breeding populations in the future. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**	Golden plover populations in the PDNP show signs of recovery from historic decline, increasing in recent years. The greatest risk to PDNP golden plover populations is loss of suitable habitat as temperatures rise. Populations will likely move northwards out of the park boundary over the next century. Effects on coastal wintering grounds will likely also be significant, with sea level rise removing habitat and causing greater construction of sea defences. Golden plover are not very adaptable, as a moorland specialist with limited space within the PDNP to move with changing conditions. However, support from conservation organisations and environmental stewardship schemes should go some way to improving their resilience. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Great crested newts – High vulnerability Great crested newts in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor current condition, and a moderate adaptive capacity. The PDNP great crested newt population appears to be stable, having recovered from heavy historical declines. Terrestrial and aquatic habitats are both essential for the survival of this species, with ponds being most at risk in the face of climate change. Their longevity and the existence of metapopulations give this species some adaptability. However much depends on land management decisions and ongoing maintenance of ponds. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Lapwing – High vulnerability** Lapwing in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a potentially improving current condition but an only moderate adaptive capacity. Lapwing in the PDNP have suffered historical decline, and their recovery has been variable despite targeted management. Some of the greatest impacts on lapwing populations will be in effects on their invertebrate prey. Drier conditions and increased flooding are likely to decrease the abundance of soil invertebrates, reducing lapwing breeding success. As a bird mostly associated with farmland, human behaviour changes will be very important for future lapwing populations – but these are difficult to predict. Lapwing have some capacity to adapt to a climate change, and this would be helped by conservation initiatives on in-bye land. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Merlin – Very high vulnerability Merlin in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor current condition, and a low adaptive capacity score.	**Mountain hares – High vulnerability** Mountain hares in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate current condition, and with a moderate adaptive capacity.

Merlin are a scarce species in the PDNP, with a small population that has not rebounded as well as some other raptors in recent years. Climate change poses a significant threat to merlin, as the PDNP and much of the UK will become unsuitable as temperatures rise. Merlin are very likely to be extinct from the PDNP by the end of the 21st century. Changes to merlin nesting habitat, especially mature heather stands may also put pressure on populations. Despite being a mobile species and able to change nesting habits, merlin are unlikely to be able to adapt enough to offset climate effects. This is due in part to insufficient support and management, but is largely due to the extent of climate impact. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**	Currently with a declining population, mountain hares are particularly vulnerable in winter as energy demands are high. Healthy habitat for shelter and food are vital for the continued survival of this species. While this is an isolated population, the high population growth rate of mountain hares gives them a good chance at recovery from climate change events. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Pied flycatchers – High vulnerability Pied flycatchers in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a moderate current condition, and a moderate adaptive capacity. Pied flycatchers in the PDNP appear to be doing reasonably well, with known populations doing better than the national average. Trophic mismatches with their nesting food sources are likely to increase as climate change shifts the timing of annual events such as migration and leaf bud burst. Climate change effects in West African wintering grounds will also be important. The moderate adaptive capacity of PDNP populations mostly relies on good management of key sites. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Ring ouzel – Very high vulnerability** Ring ouzel in the PDNP have been rated ‘very high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a declining current condition, and a low adaptive capacity. Ring ouzel population trends in the PDNP appear to be following the national trend, declining and retracting to upland locations. Changing conditions and mismatch in the timing of food availability may mean that in the future, suitable habitat can only be found north of the PDNP. Greater disturbance from increased visitor numbers may also have a significant effect. Despite their reasonable dispersal ability, ring ouzel are unlikely to adapt quickly enough to match changing conditions, and management interventions are not well known enough to counter this. **Overall potential impact rating: High** **Overall adaptive capacity rating: Low**
Short-eared owl – High vulnerability Short-eared owl in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor but recovering current condition, and a moderate adaptive capacity. Short-eared owl populations in the PDNP appear to be recovering from historical decline despite continuing threats. Climate change effects on	**Snipe – High vulnerability** Snipe in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but with a recovering current condition and a moderate adaptive capacity. Snipe populations in the PDNP appear to be increasing and recovering from historical losses. Changes in ground conditions will likely have the

their small mammal prey may have a significant impact on short-eared owls. They are a widespread and mobile migrant, so short-eared owls are quite adaptable to changing conditions. However, this may include moving out of the PDNP. Conservation actions taken in the PDNP could assist short-eared owls in adapting to changing conditions. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	biggest impact on snipe populations: both dry and waterlogged conditions will restrict access to their invertebrate prey. These effects will be particularly important during nesting season. Snipe in the PDNP mainly breed in very specific habitat, but have the potential to adapt to changing conditions. Money available through agri-environment schemes, as well as support from conservation organisations will assist greatly with snipe adaptive capacity. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Swallow – Moderate vulnerability Swallows in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but with a reasonable current condition and a high adaptive capacity. PDNP swallow populations appear to be faring well despite some recent losses. Drier conditions restricting nest building are likely to be leading stressors on future swallow populations. Changes to their wintering grounds may also have strong effects that are more difficult to address. Despite their low conservation priority and restricted funding and support, swallows have shown themselves to be very adaptable birds, already showing some adaptation to climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	**Twite – Very high vulnerability** Twite in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a very poor current condition approaching complete loss, and a low adaptive capacity. Twite are faring poorly in the PDNP, with moorland populations lost in many places and a small quarry dwelling population in the White Peak being the largest known colony. Climate change may cause twite to move out of the PDNP as they are on the south-eastern edge of their UK range here. Changes in flowering and seed setting timings of their plant food resources may cause a mismatch between twite nesting dates and seed abundance, and interrupt continuous food supply. Twite are a mobile species, but are unlikely to overcome future challenges presented to them. The greatest pressure will probably come from human land use change, so institutional and economic support will be needed to implement management interventions. Unfortunately, the resources currently available do not appear sufficient to retain twite in the PDNP. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**
Waxcap fungi – High vulnerability Waxcaps in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a variable and often unknown current condition, and only a moderate adaptive capacity.	

Waxcap grassland condition in the PDNP is variable, with some sites of national importance, but many others unknown or under-recorded. The impact of climate change on waxcap grasslands is unclear, as they are a habitat more dependent on management than climate. One factor that will be likely to have an effect is increased nitrogen deposition, which may act to reduce the extent and abundance of waxcaps. Waxcaps are not particularly adaptable as a genus, but management knowledge and application has some potential to reduce the impact of climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Increased winter rainfall	Greater flooding and waterlogging	• Some habitats or species rely on a particular level of grazing and could be impacted if land becomes less desirable for grazing management • In some areas, livestock may become concentrated on the remaining unflooded fields leading to overgrazing and poaching of ground • Overgrazing can lead to soil compaction which negatively affects invertebrates, birds and fungi and can worsen run-off effects • Overgrazing can increase nest trampling, negatively affecting birds • Additional areas of grassland may be agriculturally improved to increase availability of pasture
Drier summers	Land uneconomic for grazing	• Some habitats or species rely on a particular level of grazing and could be impacted if less land is available for grazing management
	Increased periods of drought	• Decline of wet habitats and wet ground specialist species • Reduced habitat space for freshwater species
	Lower water levels in rivers, reservoirs and ponds	• Increased concentration of nutrients in waterbodies making the habitat less suitable for freshwater species • Some ponds and river headwaters may become seasonal, reducing the available habitat space for freshwater species
	Increased frequency and severity of wildfire	• Increased erosion and loss of peat due to wildfire • Direct loss of terrestrial and aquatic plants and animals and/or reduced breeding success • Changes to the species composition of habitats, which favour fire-adapted and/or invasive species
	Higher visitor numbers	• Increased habitat damage from trampling and path erosion, and increased littering. • Increased ignition sources for wildfire • Disturbance of sensitive species, in particular by visitors with dogs

Increased annual temperatures	Reduced availability of suitable climate space	• Suitable conditions for species are likely to move northwards as well as increase in altitude, which is likely to affect Eastern Moors and South West Peak areas the most • Species already restricted to the Dark Peak or high tops may be lost entirely as they move northwards or cannot access increased altitudes • As some species are lost, others may colonise from south of the PDNP
Changes in rainfall patterns	Interference with seasonal management	• Heather burning and cutting could become more difficult and need to take place at different times of year, which could impact species that benefit from this management
Combined effects	Intensification of land management practices to counter more variable conditions	• Habitat condition and biodiversity could become poorer under intensified management
	Climate change adaptation and mitigation efforts increase	• Initiatives put in place to improve habitats for carbon capture and natural flood management through processes such as rewetting and tree planting could have a positive impact on this special quality
	Land converted to arable use from pasture	• Less land available for grazing management that some habitats or species rely on
Hotter summers	Higher water temperatures in rivers, reservoirs and ponds	• Cool-adapted species are disadvantaged
	Higher visitor numbers	• Increased visitor pressure on cooler habitats such as woodlands and waterbodies

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.4. Undeveloped places of tranquillity and dark night skies within reach of millions

Description of special quality

Bounded by large towns and cities on all sides, the PDNP has a unique position as a rural landscape accessible by a large urban population. This special quality recognises the PDNP's great opportunity, as the UK's first and most accessible national park. While not a true wilderness unchanged by human settlement, the PDNP has some dark skies and places that feel completely isolated. These are easily experienced by visitors from the surrounding built-up areas and across the UK. Tranquillity may also be found in some traditional landscapes of the PDNP, providing a contrast to busy modern life.

Features in this category: *Open access land and public access, Transport links into the National Park, Abandoned places of industry, Estate lands and designed landscapes, Lowland pastoral landscapes, High open moorland and edges, Limestone dales, Woodlands*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is highly vulnerable to climate change. Of the eight special quality features assessed, no features were rated as 'very high' on our scale, however 75% were rated as 'high'. A further 13% have been rated as 'moderate', and 13% were given a 'low' rating. Extremes of drought or flooding, along with storm damage, are some of the key factors likely to affect undeveloped places of tranquillity and dark night skies in the PDNP.

Additionally, poor or variable current condition has contributed to most of the features being rated as 'high' in terms of overall vulnerability to climate change. Current condition is usually due to non-climate factors. Past and current changes in land use leave cultural landscapes such as abandoned places of industry and geological features such as moorland edges particularly vulnerable to erosion, with follow-on nutrient flushing effects into the wider landscape.

Modelling shows small fragments of woodland with low species diversity may be lost from the PDNP. However, climate change mitigation such as woodland creation could help offset this. Transport links have the lowest vulnerability to climate change, although they may still be susceptible to extreme weather events that limit access into the PDNP. Warmer weather that sees increased visitor numbers is likely to affect the tranquility levels of many locations.

Current condition, vulnerability and adaptive capacity of features

Open access land and public access – Moderate vulnerability Open access land and public access in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varied current condition, and with moderate adaptive capacity. Erosion could be one of the key potential impacts of climate change, as many paths are susceptible to extreme weather events and the most popular routes that are heavily used already suffer from erosion. There is limited funding available particularly for larger projects. However new initiatives for fundraising such as the ‘Mend our Mountains’ campaign are having a positive impact for specific routes. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**	**Transport links into the PDNP – Low vulnerability** Transport links into the PDNP have been rated ‘low’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a reasonable current condition, and high adaptive capacity. Transport links in the PDNP are generally in good condition, but subject to some pressures including weather. Major routes are already susceptible to adverse weather with snowfall often leading to the closure of the high level routes. Increases in extreme weather conditions are therefore a key potential impact of climate change on the transport infrastructure. However, research is now being carried out by organisations responsible for transport infrastructure to look at what measures can be undertaken to increase resilience to the potential impacts of climate change. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: HIGH**
Abandoned places of industry – High vulnerability Abandoned places of industry have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, and a moderate adaptive capacity. The current condition of these features across the PDNP is variable. Designation as a scheduled monument does provide some protection but only includes a small number of these sites. Climate change could have a major impact on abandoned sites of industry with workings underground potentially at risk from storm events or changes in groundwater levels that could lead to flooding and/or collapse. While appropriate management can partially counteract climate change, only a limited amount of funding is available.	**Estate lands and designed landscapes – High vulnerability** Estate lands and designed landscapes in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and moderate adaptive capacity. Many estate lands are well managed and have ongoing maintenance and development plans. The current condition for those held in private ownership is more difficult to determine. Extreme events including heavy rainfall and flooding, but particularly drought, could have a significant impact on estate lands and designed landscapes. There is capacity for adaptation as most have a management plan or similar system in place. Some estates are also given protection through their registered status.

Overall potential impact rating: HIGH **Overall adaptive capacity rating: MODERATE**	**Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Lowland pastoral landscapes – High vulnerability Lowland pastoral landscapes in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a vulnerable current condition and moderate adaptive capacity. Lowland pastoral landscapes in the PNDP are vulnerable to changes in economic and political conditions, with agricultural intensification already affecting the historical character of many farms. One of the key potential impacts of climate change is a change in land use, particularly a turn to more arable usage with fields ploughed and remaining flower rich grasslands lost. Many small dairy farms have already been lost and been replaced by larger holdings with an increased demand for larger building and fields, together with fewer meadows and more fodder crops. However, sustainable and sensitive farming techniques could be implemented more widely to help offset some climate change impacts. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**High open moorland and edges – High vulnerability** High open moorland and edges in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a moderate adaptive capacity. High open moorland and edges in the PDNP are in generally poor condition, with blanket bog in the worst state ecologically and hydrologically. They are particularly sensitive to hotter, drier summers and the resulting wildfire and erosion potential. Moorland edges also often have a high heritage significance, and surface and buried archaeological features are very sensitive to factors such as changes in vegetation, soil erosion and wildfire. High open moorland and edges have a moderate adaptive capacity, but realising this is reliant on economic subsidy and management regime agreement in the long term, unless radical changes to the landscape are allowed to take place. The adaptive capacity of archaeological sites is lower once they have reached the point of being exposed through soil erosion or wildfire for example. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Limestone dales – High vulnerability Limestone dales in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity. The condition of limestone dales in the PDNP is generally good but subject to some pressures. Changes to water levels could have a major impact on habitat and how the land is used in the future. This will affect the appearance and	**Woodlands – High vulnerability** Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented current condition, and a moderate adaptive capacity. Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under SSSI protection faring better. Smaller woodlands

appeal of the landscape. Damage to parts of this feature will be irreversible, reducing its adaptive capacity, however there are schemes which could help with adaptation and a large proportion of the sites are formally protected. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Drier summers	Higher visitor numbers	• Increased erosion across all landscapes and features, from abandoned places of industry to woodland • Litter and wildfire risk on high open moorlands could increase • Disturbance of sensitive species, in particular by visitors with dogs • Wildlife encounters may be better in some areas as animals get used to higher volumes of people
	Increased periods of drought	• Increased demand for water abstraction in the limestone dales • Pressure placed on waterways could negatively impact visitor facilities and affect the aesthetics of rivers and streams that people want to visit • Some affected areas may become less desirable to visit or have issues with visitor capacity • Erosion rates of peat in the high open moorland coupled with changes to plant composition may alter desirability for recreational use in some areas • Visual changes may be prominent in lowland pastoral landscapes, limestone dales and woodlands • Wildlife inhabiting these landscapes could be affected, with some species being lost or temporarily moving elsewhere in search for water • Aesthetics may change but the overall tranquillity and dark night skies are unlikely to be affected
Combined effects	Land use change	• Farming economics may bring about shifts in stocking levels and management techniques which could change the landscape character and alter the visitor experience and sense of escape
	Increased threat from pathogens and pests	• The effect of ash dieback disease in woodlands may be accelerated due to increased stress • Other plant diseases such as *Phytophthora* may become more prevalent, placing the long-term health and diversity of some habitats at risk

		• Landscape aesthetics may be altered as trees and hedgerows are lost or damaged
	Climate change adaptation and mitigation efforts increase	• Increased pressure for the introduction of renewable energy sources such as wind farms, solar panels and hydro electric generators. • Noise levels and visual impact could affect the visitor experience • Woodland planting may be used to increase carbon sequestration and to aid flood management • Moorland restoration efforts in the Dark Peak and South West Peak may be in higher demand to reduce flood risk downstream • Moorland and woodland habitats would be enhanced, providing spaces that are more resilient and enabling visitors to enjoy tranquillity and dark night skies
Hotter summers	Higher visitor numbers	• Increased visitor pressure on infrastructure at popular locations • Some areas are likely to lose their calm, quiet atmosphere at peak times • Reduction of sense of wilderness that attracts many visitors in the first place • Increased recreational pressure near waterways and under trees as people seek cool and shaded places • Opportunities for more outdoor events • Larger numbers of cars and changes to lighting could affect light pollution levels reducing the quality of dark night skies
Increased storm events	Intense rainfall, strong winds, and flooding	• Erosion may damage abandoned places of industry such as mining features, and moorland edges in the uplands • Wind throw damage to woodlands • Visitor access and outdoor events affected • Changes to landscape aesthetics and visitor access could affect the visitor experience and the sense of tranquillity people find

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.5. Landscapes that tell a story of thousands of years of people, farming and industry

Description of special quality

The PDNP is a landscape has been used by humans for thousands of years. This is most evident in the ancient towns and traditionally walled fields, as well as the traces of industry across the PDNP. One of the most recognisable symbols of the PDNP is the millstone, once used in industry but now found scattered across the moors. Even the apparently wild landscapes of the PDNP show the evidence of human alteration to the informed eye; the open moorland and rolling grassland being a product of woodland clearances thousands of years ago. The patterns of enclosure show the history of farming in the PDNP, with some boundaries showing the outlines of medieval strip fields.

Features in this category: *Bridges, Farmsteads, Field barns and outfarms, Prehistoric burial mounds and ceremonial monuments, Prehistoric settlements and field systems, Abandoned places of industry, Boundaries and patterns of enclosure, Estate lands and designed landscapes, Lead mining, Managed moorland, Buried soils, archaeological remains and deposits, High open moorland and edges, Palaeoenvironmental remains and sequences, Show caves and caverns, Meadows, Dewponds and other ponds, Reservoirs and water management*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is highly vulnerable to climate change. Of the 18 special quality features assessed, 6% have been rated as 'very high' on our scale and almost 70% were rated as 'high'. The rest have been rated as 'moderate', and no features were given a 'low' rating. Changes to rainfall patterns, with wetter winters and drier summers as well as extremes of drought or flooding, are some of the key factors likely to affect historical landscapes in the PDNP.

Additionally, poor or variable current condition has contributed to many features being rated as 'very high' or 'high' in terms of overall vulnerability to climate change. Current condition is usually due to non-climate factors. Past and current land use changes affect most of the features within this special quality, as the use of various buildings, field systems, and ponds continues to fluctuate in line with economic and technological shifts. Maintenance and repair of many of these features is important to increase their resilience to change, along with designations and financial assistance for the most vulnerable sites.

Soil and ground condition across the PDNP are particularly vulnerable to changes in rainfall patterns. This is likely to affect the stability of bridges and prehistoric ceremonial monuments, along with the preservation environment around archaeological and palaeoenvironmental remains. The combined effects of climate change could threaten many historical features both above and below ground.

Current condition, vulnerability and adaptive capacity of features

Bridges – Moderate vulnerability Clapper and packhorse bridges in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to a moderate sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity. The impact of changed precipitation regimes is likely to be the most significant for these features. An increase in erosion and the potential for structural damage through attrition or large flooding incidents could be detrimental, making all bridges more vulnerable. While traditional building materials and techniques have displayed a good deal of resistance to date, and it should be possible to repair some damage, irreplaceable historic information may be lost. There are a limited number of these features, and they have limited diversity. Non-designated bridges on privately owned land or not carrying public rights of way will possibly be the most vulnerable of these features as they are often little understood and may have limited monitoring and maintenance. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**	**Farmsteads – Moderate vulnerability** Farmsteads in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables but a positive current condition, and a high adaptive capacity. Although there are farmsteads which are disused derelict or have been changed in use, the position within the PDNP is better than the status nationally. Farmsteads are sensitive to changes in agriculture, and although some funding is available for their conservation it is very limited and their future is uncertain. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**
Field barns and outfarms – Moderate vulnerability Field barns and outfarms in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to a high sensitivity and exposure to climate change variables and a variable condition, but with a high adaptive capacity. However, changes to farming practices have led to these buildings being subject to high rate of abandonment and loss. Changes to the economics of farming and farming practices due to climate change may drive modernisation of	**Prehistoric burial mounds and ceremonial monuments – High vulnerability** Prehistoric ceremonial monuments in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change, a variable current condition and a moderate adaptive capacity. Prehistoric burial mounds and ceremonial monuments are in a vulnerable condition, with only half of those known intact. Climate change has the potential to accelerate damage to those structures remaining. Increased damage and

some historical farm buildings, altering the traditional character. Greater extremes of temperature may also be damaging to buildings exposed to the elements. Despite this the position in the PDNP is much better than the picture nationally assisted by the diverse location and layouts. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	attrition rates caused by expansion and contraction of stone and soil structures have the potential to play a role in the collapse of internal chambers. Increased visitor numbers in the PDNP, burrowing animals, and future changes to farming practices may be some of the most important climate driven factors to impact these features. These features are an irreplaceable and finite resource, susceptible to damage and loss. However appropriate protections and management should be able to at least partially offset the impacts of climate change. Neolithic sites are likely to be the most vulnerable as an overall resource due to their rarity, while unscheduled and unknown sites will be vulnerable because appropriate management actions are less likely to be put in place. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Prehistoric and Romano-British settlements, field systems and cairnfields Prehistoric and Roman-British settlements, field systems and cairnfields in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varying current condition, and a moderate adaptive capacity. The current condition of all features is unknown as many have yet to be discovered, but of those that are known only 13% are in poor condition. Sites may be vulnerable to climate change following changes in farming practices, direct erosion and erosion of the soils around the features, and further growth of nuisance plant species. There are appropriate management and conservation actions to help these features adapt to climate change, however it is expected that a significant proportion of these sites have not been formally designated and therefore adaptations are less likely be put in place.	**Abandoned places of industry – High vulnerability** Abandoned places of industry have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, and a moderate adaptive capacity. The current condition of these features across the PDNP is variable. Designation as a scheduled monument does provide some protection but only includes a small number of these sites. Climate change could have a major impact on abandoned sites of industry with workings underground potentially at risk from storm events or changes in groundwater levels that could lead to flooding and/or collapse. While appropriate management can partially counteract climate change, only a limited amount of funding is available. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Overall potential impact rating: MODERATE **Overall adaptive capacity rating: MODERATE**	
Boundaries and patterns of enclosure – High vulnerability Boundaries and patterns of enclosure have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an often poor general condition, and a moderate adaptive capacity. It is difficult to ascertain the overall current condition of dry stone walls as it is varied. However the condition of hedgerows is viewed as poor. Extreme weather is one of the key potential impacts increasing deterioration and maintenance costs leading to a greater risk of abandonment. Another is changes to land use, which may mean boundaries are removed to enlarge fields. Changing farming practices such as an increase in ploughing may affect earthwork features. Walls in poor condition are also often used as a source of stone to repair other walls. There is limited funding available to improve these features and there is currently a shortage in terms of the number of people with the necessary dry stone walling skills needed for management and maintenance. Even the repair and rebuilding of walls, whilst retaining the landscape appearance, can remove or alter historic information that is very valuable (such as the physical relationships between features, or distinctive construction styles). Planting could improve hedgerows condition by filling in gaps and diversifying species. If not designated, prehistoric field systems are vulnerable to landscape change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Estate lands and designed landscapes – High vulnerability** Estate lands and designed landscapes in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and moderate adaptive capacity. Many estate lands are well managed and have ongoing maintenance and development plans. The current condition for those held in private ownership is more difficult to determine. Extreme events including heavy rainfall and flooding, but particularly drought, could have a significant impact on estate lands and designed landscapes. There is capacity for adaptation as most have a management plan or similar system in place. Some estates are also given protection through their registered status. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Managed moorland – High vulnerability Managed moorland in the PDNP has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, and a moderate adaptive capacity. Managed moorland is in an insecure condition in the PDNP, subject to numerous pressures and often dependent on agricultural payment schemes. It will be particularly sensitive to increases in wildfire and changes in annual precipitation regimes. This is due to the huge detrimental impact that wildfire can have on these landscapes and the sensitivity of the plants to water availability. Managed moorland has some capacity to adapt, but is reliant on funding to facilitate this. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Buried soils, archaeological remains and deposits – High vulnerability** Buried soils, archaeological remains and deposits in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables. Their current overall condition is difficult to ascertain, but they have a moderate adaptive capacity. One of the key potential impacts to archaeological remains is drier summers and wetter winters which could cause direct damage and also change how the land is used. Previous drainage of bogs and other soils coupled with development, farming practices including ploughing have caused damaged these features already. Archaeological remains cannot recover once they are lost. Although work is taking place to restore PDNP wetlands, this is reliant on funding being available. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
High open moorland and edges – High vulnerability High open moorland and edges in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor ‘non-functional’ current condition, and a moderate adaptive capacity. High open moorland and edges in the PDNP are in generally poor condition, with blanket bog in the worst state ecologically and hydrologically. They are particularly sensitive to hotter, drier summers and the resulting wildfire and erosion potential. Moorland edges also often have a high heritage significance, and surface and buried archaeological features are very sensitive	**Palaeoenvironmental remains and sequences – High vulnerability** Palaeoenvironmental remains and sequences in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, and a variable current condition and a moderate adaptive capacity. The current condition of these features is largely unknown due to their hidden nature, but certain areas such as the peat bogs of the Dark and South West Peak are known to be at risk. Climate change effects that expose deposits or alter soil conditions are likely to be damaging. As these features are buried any change in the surface conditions from extreme weather events will have a key potential impact. Sediments in underground sites, fissures and caves are equally

to factors such as changes in vegetation, soil erosion and wildfire. High open moorland and edges have a moderate adaptive capacity, but realising this is reliant on economic subsidy and management regime agreement in the long term, unless radical changes to the landscape are allowed to take place. The adaptive capacity of archaeological sites is lower once they have reached the point of being exposed through soil erosion or wildfire for example. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	important and must not be overlooked. These may be particularly vulnerable to environmental change. There is very limited capacity for adaptation as once they are damaged the information that they contain cannot be recovered. However there are adaptations that can be made to help preserve the existing resource. These features are particularly significant where they can be related to other heritage features such as prehistoric settlement and field systems or human activity within caves, for example. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Show caves and caverns – Moderate vulnerability Show caves and caverns in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, a relatively stable current condition, and a moderate adaptive capacity. An increase in flooding of the caverns is one of the key potential impacts of climate change. This could mean they close for longer and more regularly resulting in the attractions possibly becoming more seasonal. Changes in water levels and associated erosion could potentially damage historic features within the caves and caverns. All four show caverns are in private ownership and appear to be reasonably sustainable businesses however it is not known what financial resources they have to invest in adaptations, and the range of changes that could be made is relatively limited. The feasibility of investing in natural flood management techniques in the catchment that feeds the caverns should be investigated.	**Meadows – High vulnerability** Meadows and associated features in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a varied current condition and highly fragmented habitats, but with a moderate adaptive capacity. Meadows are already in a poor state in the PDNP, with only a few small patches with very limited connectivity remaining. Climate change impacts are unavoidable; key plants and their associated species may be lost. Some meadow species will be unable to thrive with changes in weather, leading to habitat change. Agricultural intensification caused by pressure to grow more food may lead to further habitat loss. A mismatch between flowering and pollination timings may lead to a decrease in some plants. Pollution may cause changes to soil composition. Hay-making may become difficult due to unpredictable weather. Overall, climate change stressors are likely to lead a loss of habitat and biodiversity. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Overall potential impact rating: MODERATE **Overall adaptive capacity rating: MODERATE**	
Dew ponds and other ponds – Very high vulnerability Dew ponds and other ponds in the PDNP have been rated ‘very high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor current condition, and a low adaptive capacity. Extreme events including flood and drought could have a significant impact on this feature, reducing their functionality and potentially leading to ponds being abandoned or infilled. Dew ponds with intact historic surfaces (clay and cobbles) are becoming increasingly rare. The adaptive capacity of this feature is low as there are a limited number that are functional. PDNPA funding is currently available for pond restoration, but this is very limited. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: LOW**	**Reservoirs and water management – High vulnerability** Reservoirs and water management in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a variable current condition, and a moderate adaptive capacity. Increased rainfall could impact on reservoirs and water management features if there is not enough storage or carrying capacity. The risk of flood to areas downstream could damage historic buildings and mills. As the historic sites cannot be moved or relocated their adaptive capacity is moderate. While repairs or adaption may be possible they may result in the reduction in historic value. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Lead mining – High vulnerability Lead mining in the PDNP has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a highly variable current condition, and moderate adaptive capacity. Lead mining remains in the PDNP are in variable condition, some high value sites are in very good condition, but many other hillocks and sites of ecological interest have been degraded. Changes in the climate could have a major direct impact on these sites altering the composition of the important calaminarian grassland habitats, while increased storm events could lead to pollution further downstream and damage to remaining archaeological features. Spoil tips and workings often comprise loose soils and deposits that are	

very vulnerable to erosion by wind water and abrasion. Surface features are particularly vulnerable to agricultural improvement, such as infilling and levelling. While some calaminarian grassland species have capacity to adapt, sites are fragmented and recovery from damaging events may be slow. Archaeological features have less adaptive capacity and should be considered a non-replaceable resource. Factors which may help to partially offset climate stressors include the good diversity of archaeological features which still exist, the diverse micro-topography of the remaining lead landscape, and the relatively well-studied nature of assets in the PDNP. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	

Potential impacts of climate change

Climate projection	Effect		Potential impacts
Drier summers	Increased periods of drought	•	• Lower productivity may increase grazing damage if stocking levels are kept constant • Drought may cause drying out and exposure of buried artefacts and deposits, increasing degradation • Loss of drought sensitive plants could decrease the diversity of meadows and calaminarian grassland • White Peak dewponds may dry up and become abandoned • Underwater archaeological features may be exposed more often, leading to environmental degradation and damage from visitors • Drought sensitive trees may be lost from traditional hedgerows
	Increased wildfire risk	•	• Increase in wildfire risk could cause severe damage to PDNP uplands, especially dry heather moorland • Buried artefacts and deposits could be exposed and damaged by wildfire and subsequent erosion • Silt and soot entering reservoirs could increase the difficulty of water management
Combined effects	Land use change	•	• Higher stocking levels on less affected sites may increase grazing pressure, especially on moorland edges • White Peak meadows may be converted to permanent pasture • Intensification may damage archaeological features and deposits

			• Landholdings may be consolidated and traditional field patterns and boundaries lost • Traditional farm buildings could be converted to modern holiday homes • Managed moorland may become uneconomical and convert to other land use • Moorland management may increase to counter climate change losses, increasing moorland degradation • White Peak dewponds may become disused as they can no longer cope with drier summers and are replaced by less traditional water systems
	Increased plant growth	•	• Building foundations and structure may be damaged by increased root growth, particularly if poorly maintained • Scrub encroachment and rampant plant growth may cover ground features • Buried artefacts and deposits are at risk of root damage • Moorland edges may succeed to acid grassland assemblage • Meadows may become species poor as fast growing species dominate
Increased storm events	Intense rainfall, strong winds, and flooding	•	• Constructions on watercourses may be damaged or destroyed by flood waters • Historical water management features may be damaged or removed to reduce flood risk • Heavy rain may damage older buildings and drive modernisation • Archaeological landmarks may be damaged by storm

			rains, wind-thrown trees or covered by sediment runoff • Moorlands may experience increased erosion • Riverside and floodplain meadows may be more frequently inundated • Buried deposits could be at greater risk of exposure and degradation due to erosion by wind and water

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.6. Characteristic settlements with strong communities and traditions

Description of special quality

PDNP settlements provide a window into the past of the national park. The historical factors governing the creation and development of a settlement are often lost as development continues, but planning laws and strong communities have kept the historic cores in the PDNP relatively intact. Many buildings are now listed as a result. Settlements vary from isolated farmsteads to large manor houses in parkland. Chatsworth House can be seen today as an example of a stately home, with the nearby village of Edensor being a planned settlement for those employed by the estate. Buildings are generally built of local stone, making a White Peak house easily distinguishable from the same in the gritstone Dark Peak. The preservation of traditional communities and ways of life has allowed PDNP traditions to continue and flourish, with well dressing still a common event in summertime.

Features in this category: Boundaries and patterns of enclosure, *Building materials, Farmsteads, Field barns and outfarms, Country houses, Listed buildings, Villages associated with medieval strip fields, Local events, Transport links into the National Park, Estate lands and designed landscapes*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is moderately vulnerable to climate change. Of the ten special quality features assessed, no features were rated as ‘very high’ on our scale and only 20% were rated as ‘high’. Most features (70%) were rated as ‘moderate’, and 10% were given a ‘low’ rating. Warmer temperatures, as well as storm damage and extremes of drought or flooding, are some of the key factors likely to affect characteristic settlements in the PDNP.

Additionally, a relatively stable and well-managed current condition has meant that many features have been rated as ‘moderate’ in terms of overall vulnerability to climate change. Current condition is usually due to non-climate factors. Much of the built environment, as well as local events and transport links, are well maintained with flexibility in their long-term management and upkeep.

Fluctuating temperatures are likely to affect buildings and their contents and may lead to increased pests and pathogens at some sites. Land use changes could affect field and building usage, with changes to repair and maintenance schedules. The setting of buildings may also be affected. Limited resources may determine which settlements are able to adapt best to future climate conditions.

Current condition, vulnerability and adaptive capacity of features

Building materials – Moderate vulnerability Building materials in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a high adaptive capacity. It is hard to quantify the current condition; however building materials are susceptible to changes in weather and fluctuations in temperature. Moves to upgrade the thermal efficiency of buildings could potentially have an impact on ventilation. This may make them more susceptible to rot and insect infestation as well as changing the character of the roof scape. Skills do exist to enable buildings to be adapted and maintained for modern living, and this can be somewhat controlled through the planning systems in place. It should be possible for the PDNP to retain its vernacular and distinctive architecture despite climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	**Farmsteads – Moderate vulnerability** Farmsteads in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables but a positive current condition, and a high adaptive capacity. Although there are farmsteads which are disused, derelict or have been changed in use, the position within the PDNP is better than the status nationally. Farmsteads are sensitive to changes in agriculture, and although some funding is available for their conservation it is very limited and their future is uncertain. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**
Field barns and outfarms – Moderate vulnerability Field barns and outfarms in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to a high sensitivity and exposure to climate change variables and a variable condition, but with a high adaptive capacity. However, changes to farming practices have led to these buildings being subject to high rate of abandonment and loss. Changes to the economics of farming and farming practices due to climate change may drive modernisation of some historical farm buildings, altering the traditional character. Greater extremes of temperature may also be damaging to buildings exposed to the elements. Despite this the position in the PDNP is much better than the	**Country houses– Moderate vulnerability** Country houses and associated features in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a generally well managed current condition and a high adaptive capacity. An increase in extreme climates, pests and diseases may pose a threat to species which define the character of the gardens at these homes and the historical archives contained within them. Changes to landscape may affect people's desire to visit, decreasing the amount of resources available to protect the building and grounds from further harmful effects brought on by changes to climate. If they are well managed

picture nationally assisted by the diverse location and layouts. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	and resourced, country houses and their parkland settings have a high adaptive capacity. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**
Listed buildings – Moderate vulnerability Listed buildings in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a reasonable overall current condition, and a high adaptive capacity. Only one property in the PDNP is currently on the national Heritage at Risk register that provides information on those under threat, however it only includes Grade I and II* buildings. The PDNPA holds its own list of buildings at risk, which includes 160 listed buildings (156 Grade II and 4 Grade II*). Climate change may increase damage to these buildings from extreme weather events such as flooding and storm damage. Greater fluctuations in temperature may also damage building structure as well as foundations. The designation of listed building status does provide some protection but the very nature of the properties means that changing them to make them more thermally efficient or modifying their rainwater goods, for example, may be detrimental to what makes them special. The buildings that are likely to be most vulnerable are those which are uninhabited, or those in private ownership that have limited resources available. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	**Villages associated with medieval strip fields – Moderate vulnerability** Villages associated with medieval strip fields in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, a relatively stable current condition, and a moderate adaptive capacity. To date the dominance of pasture and lower intensity livestock farming in the PDNP has been a factor in the preservation of this feature. Strip fields are vulnerable to farming intensification in response to climate change, especially a change from pasture to arable land use. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**
Local events – Moderate vulnerability Local events in the PDNP have been rated 'moderate' on our vulnerability scale. This score	**Transport links into the PDNP – Low vulnerability**

is due to high sensitivity and exposure to climate change variables, with a relatively stable current condition, and with a high adaptive capacity. Changes in the climate could have a significant impact on local events particularly those that rely on the weather or are tied to a specific date. The majority are run by volunteers and depend upon funds raised one year to finance the following year’s event. A series of poor years could mean the event is lost entirely. In recent years a small number of events have been lost, however local events do have a high adaptive capacity as demonstrated by the Bakewell Show which changed its date and format in 2019 due to wet weather. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	Transport links into the PDNP have been rated ‘low’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a reasonable current condition, and high adaptive capacity. Transport links in the PDNP are generally in good condition, but subject to some pressures including weather. Major routes are already susceptible to adverse weather with snowfall often leading to the closure of the high level routes. Increases in extreme weather conditions are therefore a key potential impact of climate change on the transport infrastructure. However, research is now being carried out by organisations responsible for transport infrastructure to look at what measures can be undertaken to increase resilience to the potential impacts of climate change. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: HIGH**
Estate lands and designed landscapes – High vulnerability Estate lands and designed landscapes in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and moderate adaptive capacity. Many estate lands are well managed and have ongoing maintenance and development plans. The current condition for those held in private ownership is more difficult to determine. Extreme events including heavy rainfall and flooding, but particularly drought, could have a significant impact on estate lands and designed landscapes. There is capacity for adaptation as most have a management plan or similar system in place. Some estates are also given protection through their registered status.	**Boundaries and patterns of enclosure – High vulnerability** Boundaries and patterns of enclosure have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an often poor general condition, and a moderate adaptive capacity. It is difficult to ascertain the overall current condition of dry stone walls as it is varied. However the condition of hedgerows is viewed as poor. Extreme weather is one of the key potential impacts increasing deterioration and maintenance costs leading to a greater risk of abandonment. Another is changes to land use, which may mean boundaries are removed to enlarge fields. Changing farming practices such as an increase in ploughing may affect earthwork

Overall potential impact rating: HIGH **Overall adaptive capacity rating: MODERATE**	features. Walls in poor condition are also often used as a source of stone to repair other walls. There is limited funding available to improve these features and there is currently a shortage in terms of the number of people with the necessary dry stone walling skills needed for management and maintenance. Even the repair and rebuilding of walls, whilst retaining the landscape appearance, can remove or alter historic information that is very valuable (such as the physical relationships between features, or distinctive construction styles). Planting could improve hedgerows condition by filling in gaps and diversifying species. If not designated, prehistoric field systems are vulnerable to landscape change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Combined effects	Land use change	• Changes to ground conditions may favour more intensive farming methods such as conversion of pasture to arable • Unsuitable conditions may lead to abandonment of some agricultural areas or to an increase in the size of areas being managed as smaller landholdings are consolidated • Enlargement of fields would lead to hedgerows and walls being removed and the traditional patterns of enclosure being lost • Larger landholdings could lead to more industrialised techniques being used, and landlords that may not live in the area managing the land. Traditional methods of farming and local relationships with the land may be lost • Some traditional farm buildings may be abandoned or replaced • Some buildings could be repurposed for new opportunities such as holiday cottages • Modernisation of buildings may cause issues with damp and rot if ventilation is reduced
	Increased threat from pathogens and pests	• Increase in insect pests and mould growth, affecting the structure and interior of buildings from field barns to country houses • Wooden buildings are particularly susceptible to insect pests, rot, and fungus • Culturally important collections and interior fixtures in country houses may be damaged or lost • Damage will require intrusive renovation work that may affect the people who live or work there • Plants may become increasingly vulnerable to new pathogens that spread into parklands (areas with low plant diversity are particularly at risk) • Pest outbreaks may be increased further as visitors from beyond the park boundary unwittingly bring in pests or pathogens while exploring any of these sites

	Increased plant growth	• Increased plant growth of some species could affect the structural integrity of buildings and the maintenance levels needed in gardens and parklands • Plant compositions may be altered affecting landscape aesthetics • Increased growth of species such as ivy and moss may damage garden ornaments and walls
	Changes in soil stability	• Greater subsidence in soils could cause historical buildings to become unstable, with damage done to the structure and repair work needed • Damage to isolated farm buildings may go unnoticed and unrepaired • Transport links may be affected by ground subsidence. Roads in particular, especially those running alongside rivers or on shale measures, are at risk of collapse • Access may be affected as routes are closed for repairs, or in extreme cases permanently closed
Increased storm events	Intense rainfall, strong winds, and flooding	• Historical buildings, including both listed buildings and traditional farm buildings, are likely to be damaged • Damage to buildings and their interiors may be amplified due to the historic nature of guttering and roofing styles, and in most cases the inability to update these structures • Wind damage may affect chimneys and spires especially if poorly maintained • Some traditional farm buildings may be abandoned or replaced • Gardens, parklands, and buildings may be more susceptible to pests and disease due to water damage or increased stress. Some may be lost or damaged • Parkland trees and traditional boundaries could be affected, altering landscape aesthetics • In parklands greater erosion on riverbanks caused by floodwaters and storm pulses may contribute to subsidence of neighbouring land • Access may be affected, with road and rail closures during storms and afterwards to repair damages. Those

		near rivers or containing bridges are most at risk • Local events may have low attendance or be cancelled

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.7. An inspiring space for escape, adventure, discovery and quiet reflection

Description of special quality

The PDNP is a key destination for those seeking to connect with the landscape in a way not possible in an urban setting. Whether they seek adventure in the crags and caves or discovery in the quiet wooded dales and high open moors, the PDNP provides a space for escape from everyday life. Renowned worldwide for its unique landscapes, ecology, and potential for outdoor recreation, visitors from across the UK and abroad find solace in the PDNP. Recreation is facilitated by open access to most of the open moorland and many of the dales.

Features in this category: *Country houses, Paths, tracks and trails, Local events, Open access land and public access, Transport links into the National Park, High open moorland and edges, Limestone dales, River valleys, Show caves and caverns, Heather moorland and mixed heath, Limestone grassland, Woodlands*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is moderately vulnerable to climate change. Of the 12 special quality features assessed, no features have been rated as 'very high' on our scale but 33% were rated as 'high'. The majority (58%) have been rated as 'moderate', and only 8% were given a 'low' rating. Greater weather extremes, with more frequent and severe storm, flood, and drought events are some of the main factors likely to affect access to the outdoors in the PDNP.

Storm damage and flooding is likely to affect the landscape of the PDNP, with increased weathering affecting crags and edges, and flood conditions causing closure of show caves. Flooding will also affect transport links and access into and around the PDNP, and effect closures of some popular destinations. Drought would affect many habitats of the PDNP, causing them to become degraded and less appealing to visitors.

Climate change may also affect these features indirectly. Higher visitor numbers during hotter drier summers may put pressure on visitor infrastructure and increase damage to sensitive areas. In the case of open moorland, this could be through increased fire ignition sources causing wildfire during drought. Warmer wetter conditions may increase the spread of pathogens and pests due to environmental stress. This may cause the loss of veteran trees from parkland and woodland.

Current condition, vulnerability and adaptive capacity of features

Country houses– Moderate vulnerability

Country houses and associated features in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a generally well managed current condition and a high adaptive capacity.

An increase in extreme climates, pests and diseases may pose a threat to species which define the character of the gardens at these homes and the historical archives contained within them. Changes to landscape may affect people's desire to visit, decreasing the amount of resources available to protect the building and grounds from further harmful effects brought on by changes to climate. If they are well managed and resourced, country houses and their parkland settings have a high adaptive capacity.

Overall potential impact rating: HIGH
Overall adaptive capacity rating: HIGH

Paths, tracks and trails – Moderate vulnerability

Paths, tracks and trails in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varying current condition, and a moderate adaptive capacity.

The condition of routes often depends on their popularity with those heavily used becoming worn quite quickly and needing more maintenance and upkeep. Routes are sensitive to severe weather including wind and rain that can cause erosion. Increases in this damage due to climate change pose a significant risk to their condition. Damage to the physical infrastructure such as bridges may also occur. However, both the constituent highway authorities and PDNPA work to maintain routes and while funding is limited, campaigns have successfully raised money for specific work such as the Great Ridge.

Overall potential impact rating: MODERATE
Overall adaptive capacity rating: MODERATE

Local events – Moderate vulnerability

Local events in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively stable current condition, and with a high adaptive capacity.

Changes in the climate could have a significant impact on local events particularly those that rely on the weather or are tied to a specific date. The majority are run by volunteers and depend upon funds raised one year to finance the following year's event. A series of poor years could mean the event is lost entirely.

In recent years a small number of events have been lost, however local events do have a high

Open access land and public access – Moderate vulnerability

Open access land and public access in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varied current condition, and with moderate adaptive capacity.

Erosion could be one of the key potential impacts of climate change, as many paths are susceptible to extreme weather events and the most popular routes that are heavily used already suffer from erosion.

There is limited funding available particularly for larger projects. However new initiatives for

adaptive capacity as demonstrated by the Bakewell Show which changed its date and format in 2019 due to wet weather. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	fundraising such as the 'Mend our Mountains' campaign are having a positive impact for specific routes. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**
Transport links into the PDNP – Low vulnerability Transport links into the PDNP have been rated 'low' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a reasonable current condition, and high adaptive capacity. Transport links in the PDNP are generally in good condition, but subject to some pressures including weather. Major routes are already susceptible to adverse weather with snowfall often leading to the closure of the high level routes. Increases in extreme weather conditions are therefore a key potential impact of climate change on the transport infrastructure. However, research is now being carried out by organisations responsible for transport infrastructure to look at what measures can be undertaken to increase resilience to the potential impacts of climate change. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: HIGH**	**High open moorland and edges – High vulnerability** High open moorland and edges in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a moderate adaptive capacity. High open moorland and edges in the PDNP are in generally poor condition, with blanket bog in the worst state ecologically and hydrologically. They are particularly sensitive to hotter, drier summers and the resulting wildfire and erosion potential. Moorland edges also often have a high heritage significance, and surface and buried archaeological features are very sensitive to factors such as changes in vegetation, soil erosion and wildfire. High open moorland and edges have a moderate adaptive capacity, but realising this is reliant on economic subsidy and management regime agreement in the long term, unless radical changes to the landscape are allowed to take place. The adaptive capacity of archaeological sites is lower once they have reached the point of being exposed through soil erosion or wildfire for example. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Limestone dales – High vulnerability Limestone dales in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate	**River valleys – Moderate vulnerability** River valleys in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate

change variables, a variable current condition, and a moderate adaptive capacity. The condition of limestone dales in the PDNP is generally good but subject to some pressures. Changes to water levels could have a major impact on habitat, how the land is used in the future, and on the archaeological evidence of how the land was used in the past This will affect the appearance and appeal of the landscape. Damage to parts of this feature will be irreversible, reducing its adaptive capacity, however there are schemes which could help with adaptation and a large proportion of the sites are formally protected. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	change variables, coupled with a variable current condition, but with a high adaptive capacity. River valleys in the PDNP are generally in functional condition, though as active hydrological systems changes are fast. An increase in rainfall intensity and flooding is the key potential impact of climate change in river valleys. However, natural flood management schemes are part of the Department for Environment, Food and Rural Affairs (DEFRA's) 25-year plan and there are multiple management strategies that could be implemented to increase significantly the adaptive capacity of river valleys. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**
Show caves and caverns – Moderate vulnerability Show caves and caverns in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, a relatively stable current condition, and a moderate adaptive capacity. An increase in flooding of the caverns is one of the key potential impacts of climate change. This could mean they close for longer and more regularly resulting in the attractions possibly becoming more seasonal. Changes in water levels and associated erosion could potentially damage historic features within the caves and caverns. All four show caverns are in private ownership and appear to be reasonably sustainable businesses however it is not known what financial resources they have to invest in adaptations, and the range of changes that could be made is relatively limited. The feasibility of investing in natural flood management	**Heather moorland and mixed heath – High vulnerability** Heather moorland and mixed heath in the Peak District National Park has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively poor but recovering current condition, and a moderate adaptive capacity. Current heath condition in the PDNP is generally poor due to historical stressors and poor management. Modelling suggests that areas such as Eyam Moor and heathland around Chatsworth (for example Brampton East Moor) are likely to be some of the most vulnerable to climate change due to their south-easterly location and lower altitude. Changes in human behaviour may have an important impact on this managed environment. Less biodiverse areas are likely to have the lowest adaptive capacity, meaning moorland with high heather dominance is at risk from climate change. Heathland does however have the advantage of economic and organisational resources dedicated to its conservation, and has high connectivity across

techniques in the catchment that feeds the caverns should be investigated. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**	large areas. Large areas are protected under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations. In the future, PDNP moorlands are likely to become important habitat for species that currently have a more southerly distribution, such as the Dartford warbler. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Limestone grassland – Moderate vulnerability Limestone grassland in the PDNP has been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but also a high adaptive capacity. Limestone grassland in the PDNP has a limited extent, but much of what remains is protected by Site of Special Scientific Interest (SSSI) designation. Overall habitat persistence is likely to be determined by non-climate or indirect human factors, for example changes in agricultural economics, with areas such as the dales likely to be impacted. The iconic Jacob's-ladder grassland may be particularly vulnerable and in need of conservation actions. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: HIGH**	**Woodlands – High vulnerability** Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented current condition, and a moderate adaptive capacity. Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under Site of Special Scientific Interest (SSSI) protection faring better. Smaller woodlands with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Hotter, drier summers	Higher visitor numbers	• Heat stress in visitors may become more likely during hot dry summers • Damage to sensitive habitats may increase with visitor pressure • Increased ignition sources for wildfire • PDNP infrastructure may be unable to cope with greater visitor numbers • More visitors could be able to experience the PDNP
	Increased periods of drought	• Greater prevalence of drought tolerant plants on high moorland may increase heather dominance • Drought conditions may promote peat decomposition and increase the rate of erosion in low plant cover sites • Estate parklands may be affected as drought sensitive plants die off and brown patches develop • White Peak meadows and grassland could lose drought sensitive plants and have generally poor growth during drought.
Combined effects	Increased threat from pathogens and pests	• Ornamental trees and plants in parkland could be more susceptible to disease due to increased environmental stress • Woodland trees may be more susceptible to disease due to environmental stress • Country houses may be at increased risk from pest infestations, especially during wet winters • Livestock diseases may spread more easily as livestock are under increased stress, especially during wet winters
Increased storm events	Intense rainfall, strong winds, and flooding	• More frequent high waters could mean that show caves are closed more often • Flash floods in White Peak river valleys could cause reduced access and danger to visitors • Temporary road and rail closures due to storms may increase, limiting access. • Infrastructure damage may cause long term closures for repairs • Flooding on paths may leave some areas inaccessible

		• Pre-emptive closures due to public safety risks may occur on popular routes and locations • Estate lands are vulnerable to storm damage, with flooding of the grounds and damage to the buildings potentially increasing • Local events may be cancelled more often due to unpredictable weather • Increased weathering of limestone may cause rock falls, altering the landscape and reducing access

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

4.8. Vital benefits for millions of people that flow beyond the landscape boundary

Description of special quality

The PDNP is an asset not only to those living nearby, but also further afield in the UK and around the world. As well as the obvious benefits to the mental and physical health of its visitors, the ecosystem services that the PDNP provides are benefits that many take for granted. Reservoirs provide water to the nearby towns and cities, and habitats can reduce the flood risk downstream. The blanket bog of the PDNP contains a large carbon store in the form of peat, and woodlands are living biomass. Restoration of ecological function will enable these habitats to retain and absorb more carbon in the future.

Features in this category: *Paths, tracks and trails, Open access land and public access, Transport links into the national park, Healthy soil, Blanket bog, Wet woodland, Woodlands, Good water quality, Reservoirs and water management, Rivers and streams*

Below is a summary of the some of the more significant impacts that climate change could have on this special quality.

Overall vulnerability of special quality

This special quality is highly vulnerable to climate change. Of the ten special quality features assessed, 10% have been rated as ‘very high’ on our vulnerability scale and 60% were rated as ‘high’. 20% have been rated as ‘moderate’, and only 10% were given a ‘low’ rating. An increase in the frequency and severity of storms and associated damage, and greater wildfire risk during hot dry summers may be the main effects of climate change on this special quality.

The current condition of this special quality is variable, with the poorest condition in the highly fragmented wet woodland and heavily degraded blanket bog. Degraded blanket bog is unable to provide carbon storage, water filtration, or flood reduction benefits. Water quality downstream of degraded blanket bog is affected by peat erosion, but in other areas is much better. Access to the landscape of the PDNP is currently well facilitated, with visitors from the nearby urban centres able to easily access many areas.

Storms may cause damage to the important habitats of the PDNP and limit their ability to provide ecosystem services. For example, increased loss of peat from degraded blanket bog during more frequent storm events could limit the PDNP’s ability to function as a carbon store. Downstream, water quality in reservoirs and other water bodies may be reduced as erosion increases during storms. Higher wildfire incidence may increase these effects, as more severe burns cause greater carbon loss and increase siltation of water courses from ash and erosion. Increased visitor numbers during hot dry summers may increase the wildfire risk through accidental ignition. Access for visitors to the PDNP may however be inhibited by wildfire and storm damage through closures to paths and transport routes.

Indirect effects such as higher pollutant concentrations due to low water levels and increased plant growth may also affect PDNP ecosystem services. Water quality may be reduced as heavy metal pollution spreads downstream from degraded blanket bogs through peat erosion exacerbated by droughts. Increased plant growth may negatively affect the species assemblage in the uplands, but may also benefit the carbon uptake ability of woodlands. Disease prevalence may increase during times of environmental stress, causing some trees to die off.

Current condition, vulnerability and adaptive capacity of features

Paths, tracks and trails – Moderate vulnerability Paths, tracks and trails in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varying current condition, and a moderate adaptive capacity. The condition of routes often depends on their popularity with those heavily used becoming worn quite quickly and needing more maintenance and upkeep. Routes are sensitive to severe weather including wind and rain that can cause erosion. Increases in this damage due to climate change pose a significant risk to their condition. Damage to the physical infrastructure such as bridges may also occur. However, both the constituent highway authorities and PDNPA work to maintain routes and while funding is limited, campaigns have successfully raised money for specific work such as the Great Ridge. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**	**Open access land and public access – Moderate vulnerability** Open access land and public access in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varied current condition, and with moderate adaptive capacity. Erosion could be one of the key potential impacts of climate change, as many paths are susceptible to extreme weather events and the most popular routes that are heavily used already suffer from erosion. There is limited funding available particularly for larger projects. However new initiatives for fundraising such as the ‘Mend our Mountains’ campaign are having a positive impact for specific routes. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: MODERATE**
Transport links into the PDNP – Low vulnerability Transport links into the PDNP have been rated ‘low’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a reasonable current condition, and high adaptive capacity. Transport links in the PDNP are generally in good condition, but subject to some pressures including weather. Major routes are already susceptible to adverse weather with snowfall often leading to the closure of the high level routes. Increases in extreme weather conditions are therefore a key potential impact of climate change on the transport infrastructure.	**Healthy soil – High vulnerability** Healthy soil has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a varied current condition, and a moderate adaptive capacity. Soil health in the PDNP is likely to have followed the general nationwide decline over the past 50 years, with Dark Peak peat soils being in the worst condition. Erosion caused by extreme droughts and storms are one of the major potential impacts on healthy soils. A change in soil moisture levels and chemistry have the potential for a significant impact on soil biota and therefore health.

However, research is now being carried out by organisations responsible for transport infrastructure to look at what measures can be undertaken to increase resilience to the potential impacts of climate change. **Overall potential impact rating: MODERATE** **Overall adaptive capacity rating: HIGH**	While some soils can recover without intervention, most will require active management steps to be taken. Replenishing organic matter and making radical changes to landscape level management including the creation of woodland, scrub and diverse flower-rich meadows would increase the adaptive capacity of soils. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Blanket bog – Very high vulnerability Blanket bog and associated features in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a low adaptive capacity. Historically in an extremely degraded condition, many areas are recovering under SSSI and SAC designations and through landscape scale conservation works. Areas undergoing conservation works are likely to be less vulnerable than those which are not; and modelling suggests that the lower altitude bogs on the eastern edge of the Dark Peak may be among the most vulnerable areas, whilst the more continuous and higher altitude areas in the north of the PDNP may be less vulnerable. The area and quality of active blanket bog in the PDNP may be reduced by climate change. **Overall impact rating: HIGH** **Overall adaptive capacity rating: LOW**	**Wet woodland – High vulnerability** Wet woodland in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor, highly fragmented current condition, and a moderate adaptive capacity. Wet woodlands in the PDNP are already highly fragmented, but many of the remaining patches are in good condition. Wet woodlands with low tree species diversity are likely to more vulnerable than those that are more diverse. The area of wet woodland in the PDNP may be reduced by climate change. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Woodlands – High vulnerability Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented	**Good water quality – High vulnerability** Good water quality in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate

current condition, and a moderate adaptive capacity. Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under Site of Special Scientific Interest (SSSI) protection faring better. Smaller woodlands with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	current condition, and a moderate adaptive capacity. Increased sedimentation and nutrient leaching may negatively affect water quality in the future. Furthermore, increased nutrient availability coupled with increased erosion and disturbance may facilitate increases in non-native invasive species. Good water quality in the PDNP has been attributed a moderate adaptive capacity. This is due to strong legislation and regulatory processes being in place and the potential for catchment wide management policies to positively impact water quality. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**
Reservoirs and water management – High vulnerability Reservoirs and water management in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a variable current condition, and a moderate adaptive capacity. Increased rainfall could impact on reservoirs and water management features if there is not enough storage or carrying capacity. The risk of flood to areas downstream could damage historic buildings and mills. As the historic sites cannot be moved or relocated their adaptive capacity is moderate. While repairs or adaption may be possible they may result in the reduction in historic value. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**	**Rivers and streams – High vulnerability** Rivers and streams in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a reasonable current condition, and a moderate adaptive capacity. Most major rivers and streams are in a relatively good condition, with localised contamination and invasive species issues. The greatest effects on watercourses are likely to be from changes in precipitation cycles. Watercourses will become more variable, with higher flow in winter and lower flow in summer. Freshwater plant and animal communities are likely to be altered by these changes. Higher temperatures are also likely to affect freshwater communities, with suitable climate space moving northwards and upstream, and warmer conditions causing changes in water chemistry. Rivers and streams are relatively adaptable, with freshwater species having developed dispersal techniques and the watercourses having diverse forms. Much legislation exists to protect and improve rivers and streams, and some funding is available for

	water quality and flood management works, which will improve river and stream resilience. **Overall potential impact rating: HIGH** **Overall adaptive capacity rating: MODERATE**

Potential impacts of climate change

Climate projection	Effect	Potential impacts
Drier summers	Higher visitor numbers	• Increased ignition sources for wildfire
	Increased frequency and severity of wildfire	• Dry heather or grass moorlands of the Dark and South West Peak are particularly at risk • Damage to carbon stores in the PDNP • Loss of vegetation cover combined with ash and sediment entering watercourses could decrease water quality and require increased treatment • Severe wildfire events can burn large amounts of peat, releasing carbon that will take years to replace (even in active blanket bog) • Access to the PDNP could be interrupted by wildfire burns, the creation of high-risk exclusion areas, or post burn restoration • Erosion of bare peat may be accelerated after wildfire burns • Restoration works could be set back significantly, potentially requiring a full program of works before the previous condition is restored • Wildfire may also affect woodland; a less common occurrence but still damaging to carbon stores
Changes in rainfall patterns	Nutrient concentration and flushing	• **Eutrophication** in stagnant areas from low flows in summer • Pollutants such as heavy metals may be concentrated • Nutrient depletion through flushing in winter altering the freshwater species assemblage and its filtering capacity • Decline in water quality • Nitrogen accumulation in blanket bogs could lead to a shift in plant species composition and potential loss of carbon from drier peat
Combined effects	Increased threat from pathogens and pests	• Damaged and stressed trees will be more susceptible to disease

	Increased plant growth	• Species assemblages of habitats may be altered • Greater uptake and storage of carbon in habitats such as woodlands • Reduced water quality as non-native species expand and create bare ground vulnerable to erosion during winter dieback • Infrastructure and access routes into and within the PDNP may be affected
Increased storm events	Intense rainfall, strong winds, and flooding	• Erosion may cause water quality in watercourses and reservoirs to decrease, leading to an increase in water treatment costs • Erosion of peat could lead to increased gullying in blanket bogs and the release of stored carbon, making peatland habitat restoration works more difficult, or reversing early stage projects, and reducing the ability of the PDNP to act as a carbon sink • Woodland trees could be damaged or killed by wind throw or root exposure • Damage to transport links and infrastructure is likely to affect visitor access, preventing physical exercise and recreation • Visitor traffic could become concentrated at fewer sites that are more accessible, reducing the mental health benefits of wild places and a feeling of escape

Key recommendations for adaptation

For key recommendations related to this special quality, see appendix 5.

5. The feature assessments

5.1. Navigating the feature assessments

[THE TEXT IN THIS SECTION WILL BE USED TO ANNOTATE AN EXAMPLE FEATURE ASSESSMENT PAGE]

Each feature assessment is laid out in the same way:

1. **A map** – this shows in which PDNP National Character Areas the feature is typically found
2. **'Overall vulnerability rating'** – this quick-glance box gives the headline vulnerability result (Very Low, Low, Moderate, High or Very High) and is a combination of the ratings for potential impacts of climate change and adaptive capacity (6 and 7 below)
3. **'Feature description'** – this gives a full description of what we assessed
4. **'How vulnerable is/are**…' – this discusses and summarises the overall vulnerability ratings (Very Low, Low, Moderate, High or Very High) for potential impacts and adaptive capacity
5. **'Current condition'** – this summarises what is currently known about the feature's current condition, including climate change impacts to date and non-climate related factors
6. **'What are the potential impacts of climate change**?' – this gives a rating for potential impacts (Very Low, Low, Moderate, High or Very High) and discusses a feature's exposure to climate change as well as the possible impacts of climate change on the feature, starting with the most sensitive categories first
7. **'What is the adaptive capacity of**…?' – this gives a rating for adaptive capacity (Very Low, Low, Moderate, High or Very High) and discusses the rationale for the rating
8. **'Key recommendations for adaptation'** – this gives brief recommendations of key adaptations that could limit the impacts of climate change on the feature. These are simply possible actions to consider, not commitments made by PDNPA or its partners.

Referencing

The sources we used when researching the vulnerability of each feature are listed in the bibliography of the document. The bibliography is organised by theme and by feature, to make linking statements made about a feature to their sources easier. Each feature assessment is linked to the relevant section of the bibliography.

Certainty

Certainty about the accuracy of statements made within the assessment is shown through coding within the text. Symbols [L], [M], [H] and [VH] are used to signify low, medium, high or very high confidence in the preceding sentence or paragraph. Certainty shows the confidence in the sources of information gathered. The more higher-quality sources available and the better the agreement between them, the higher the certainty attached to a statement. For example, we assigned a [L] low certainty to a statement only supported by individual expert opinion and no academic research, whereas we assigned a [VH] very high certainty to a statement supported by multiple pieces of concurring academic research. Certainty can be distinct from likelihood, and this is explained in more detail in the 'Method' section of this document.

5.2. Built environment

Built environment

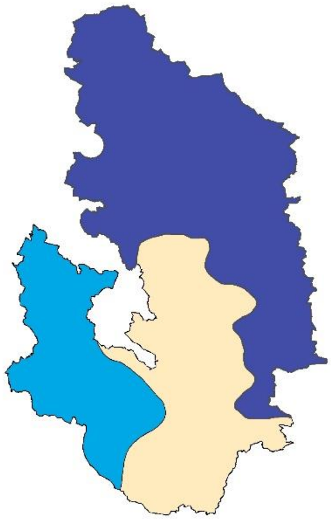
	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Building materials	High	High	**Moderate**	72
Clapper and packhorse bridges	Moderate	Moderate	**Moderate**	76
Country houses	High	High	**Moderate**	80
Farmsteads	High	High	**Moderate**	86
Field barns and outfarms	High	High	**Moderate**	90
Listed buildings	High	High	**Moderate**	94
Paths, track and trails	Moderate	Moderate	**Moderate**	98

Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

Building materials

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Traditional roofing materials, such as stone slates and Staffordshire Blue clay tiles
- Timber-frame buildings, often cruck-framed
- Gritstone, other sandstones, and limestone, in buildings and boundary walls

Special qualities:

- Characteristic settlements with strong communities and traditions

Feature description:

Building materials are distinctive and specific to the different areas of the PDNP. Traditionally gritstone, other sandstones, and limestone have been used in buildings and boundary walls, while stone slate has been used for roofs. Traditional roofing materials include gritstone slate , stone slate, Staffordshire Blue clay tile roofs, and later Welsh slate. The vernacular architecture also incorporates distinctive regional styles.

A small number of 16th century or earlier timber-frame buildings remain. Cruck-framed buildings have been found in the Dark Peak, but rare cruck-built houses and farm buildings have also been found within the White Peak.

How vulnerable are building materials?

Building materials in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a high adaptive capacity.

It is hard to quantify the current condition; however building materials are susceptible to changes in weather and fluctuations in temperature. Moves to upgrade the thermal efficiency of buildings could potentially have an impact on ventilation. This may make them more susceptible to rot and insect infestation as well as changing the character of the roof scape. Skills do exist to enable buildings to be adapted and maintained for modern living, and this can be somewhat controlled through the planning systems in place. It should be possible for the PDNP to retain its vernacular and distinctive architecture despite climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Due to the diverse nature of this category and the limited information available it is hard to quantify the current overall situation. As an example, there has been some erosion at low levels on some of the historic buildings within the PDNP such as a number of historic buildings in Bakewell built from finer grained sandstones. This is predominantly at ground level and may have been caused by dissolved salts used on the highway or other contaminants associated with roads. Loss or degradation of traditional building materials has also been associated with dereliction of properties (see 'Farmsteads' and 'Field Barns and Outfarms' feature assessments for more information) or by installation of non-traditional materials as buildings are 'upgraded' or adapted.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate change has the potential to impact the building materials that dominate the PDNP landscape. Many materials are sensitive to fluctuations of temperature, and to greater extremes of temperature, as this increases thermal expansion and contraction of wood, stone, metal, paint and lead. This may lead to accelerated attritional damage of building materials. **[M]**

Wet masonry and other building materials such as mortar are sensitive to frost especially repeated freeze-thaw and may be unable to cope with additional rainfall and higher intensity. This could damage masonry, slates and other building materials. **[M]**

Extreme events are likely to increase the damage by flooding (both from rivers and surface water); roofing materials can be damaged by high winds associated with storms while periods of sustained rainfall may cause waterlogging of the ground around buildings. **[L]**

Wetter winters and the expected increase in storm events would mean that water ingress could become more prevalent, particularly if structures have not been maintained well or adapted increasing their susceptibility to damage. **[L]**

Invasive or other species interactions

Increased annual averages and wetter warmer winters could see an increase in mould growth within and algae outside buildings. Building materials are sensitive to structural damage from any increased growth of plants and in particular insect pests, rot and fungus in wooden framed structures. Physical damage to building material may then require intrusive renovation work to be carried out. **[L]**

Increased carbon dioxide levels and other atmospheric changes may impact on invasive or nuisance plant species for example by increasing growth rates in Japanese knotweed, or trees and shrubs which can cause physical damage to building materials. Increased flooding events may increase seed dispersal of riparian invasive species. **[L]**

Human behaviour change

Moves to upgrade the thermal efficiency of buildings as climate change mitigation, by increasing insulation and installing solar panels on roofs, can have a negative impact on the building and roofscape but not necessarily on building materials. Decreased ventilation may increase rot of wooden structures and increase the likelihood of insect infestation. This in turn could lead to deterioration in wooden framed buildings and slate or stone roofs supported by wooden battens - which could lead to change in the character of the PDNP roof scape. **[L]**

Some traditional materials and building components (e.g. windows) may be less suitable for withstanding extreme events if not maintained and there may then be pressure to upgrade buildings with modern materials. The character of buildings in some areas may change and look less traditional. **[L]**

Sedimentation or erosion

The cracking of the ground in hot drought periods makes building materials susceptible to damage and the overall long term robustness of structures can be compromised. **[L]** Increases in periods of drought are likely to increase the impact of this process leading to the need for major structural repairs in places.

Some types of stone are sensitive to erosion from acid rain which may cause damage to building materials, **[L]** while wetter winters may see traditional building materials subject to an increase in erosion by hydraulic action. **[L]**

What is the adaptive capacity of building materials? ***[Overall adaptive capacity rating: HIGH]***

The planning system in place in the PDNP means changes to building materials and adaptations can be well controlled in most circumstances, but not all. Adaptations may have to comply with building regulations which could result in the loss of historic features or character. For unlisted buildings there is more limited planning control. **[VH]**

There is a good level of information about what assets exist, and the skills and techniques exist to adapt and maintain buildings in order to offset many changes in climate. Traditional buildings are already being adapted for modern living within guidance and with the special qualities of the PDNP in mind. However, there could be a lack of financial incentive to maintain or restore materials in some settings - an example being field barns which are mostly redundant for modern farming although can sometimes be re-used for other purposes. **[H]**

Most traditional building materials examined here are inherently robust and resilient, with wooden structures likely to be the most vulnerable to climate change. Leaded windows may need repairing more. It is possible to repair damage whilst maintaining character and historic significance, as long as economic resources and materials are available. **[L]**

Availability of economic resources depends on status of building, such as its historical significance, and the ownership. There are generally few resources available and these will be for some but not all buildings. **[L]**

Materials are used in a wide variety of situations across the park - and a diversity of materials is to be found in different locations. It is likely that the PDNP will retain its vernacular and distinctive architecture despite climate change. **[L]**

Key adaptation recommendations for building materials:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Provide good information on appropriate materials and encourage building owners to carry out timely maintenance and repairs.
- Create/maintain strong partnerships with external organisations to highlight materials sourcing issues, and ensure steady supply of appropriate materials (e.g. Historic England, minerals operators, architects, tradespeople).

Adapt infrastructure for future conditions

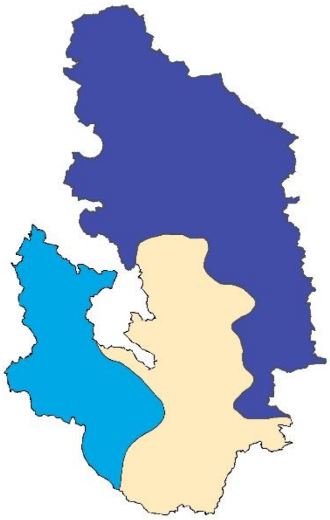
These recommendations are adaptations to physical infrastructure that should allow the features to better resist or recover from future climate change.

- Keep abreast of new research into the performance of alternative materials for future climate adaptations.
- Encourage the use and benefits of traditional materials. Review building design with the impacts of climate change in mind.

Clapper and packhorse bridges

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Clapper bridges
- Packhorse bridges

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

Clapper bridges are simple footbridges consisting of one or more large slabs of stone placed over a watercourse either directly onto each bank or supported on stone piers. In the PDNP there are a small number of clapper bridges. Examples include two gritstone bridges spanning Barbrook on the Eastern Peak District Moors, two limestone bridges located near Hassop, and impressive gritstone bridges with multiple supports over the River Bradford near Youlgreave.

Packhorse bridges are more advanced structures which were built to allow packhorses carrying goods to cross watercourses. These are slightly more abundant with 15 examples mapped by the PDNPA in locations across the Dark, White and South West Peak. In the PDNP the majority of these bridges date from the 17th, 18th and 19th centuries, although some may be significantly older. Both of these bridge types were historically used as transport infrastructure for trade and hold a high historical value. There are other bridges that are important too – sometimes medieval, that have not been addressed within the scope of this assessment.

How vulnerable are clapper and packhorse bridges?

Clapper and packhorse bridges in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to a moderate sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity.

The impact of changed precipitation regimes are likely to be the most significant for these features. An increase in erosion and the potential for structural damage through attrition or large flooding incidents could be detrimental, making all bridges more vulnerable. While traditional building materials and techniques have displayed a good deal of resistance to date, and it should be possible to repair some damage, irreplaceable historic information may be lost. There are a limited number of these features, and they have limited diversity. Non-designated bridges on privately owned land or not carrying public rights of way will possibly be the most vulnerable of these features as they are often little understood and may have limited monitoring and maintenance.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

Information about the current condition of packhorse bridges in the PDNP is incomplete, but overall condition appears to be variable. Of the 15 packhorse bridges mapped two have been reconstructed, one is known to have been ruined. Six have listed status and one has been delisted. Some bridges such as the grade II listed example at Three Shires Head are known to have been modified, in that case with the addition of a concrete roadway. Examples of known damage to bridges include the loss of coping stones and nearby surface rutting as a result of four-wheel drive vehicle use at Washgate over the River Dove. It is also known that bridges which take vehicle traffic have been subject to damage from air pollution. Clapper bridge condition information could not be found, but all examples appear to be relatively intact, and at least two are grade II listed.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Sedimentation or erosion

The close relationship of bridges to watercourses means that changes to precipitation will be likely to have the greatest potential impact in these features. Increased winter precipitation will result in higher river levels with consistently increased flow. Damage caused by hydraulic action and scouring by sediment would increase on those part of the structure in contact with water, while banks may be undermined by the same forces. This is likely to accelerate surface damage and also potentially weaken the structural integrity of the bridge over time. **[L]** An increase in the frequency and intensity of storm events in both winter and summer will have similar effects, and is also likely to increase the incidence of bridges being damaged by sediment or debris washed downstream. **[L]** Increased frequency of drought periods in the summer may also compromise the long-term robustness of structures through the cracking of the ground, particularly in clay-heavy areas. **[L]**

Direct impacts of climate change

An increase in the frequency and severity of storm events may result in the increase in direct damage to bridge structures by hydraulic action from precipitations **[L]** although conversely a reduction in freeze-thaw events during warmer winters may slow some damage. **[L]**

Invasive or other species interactions

Increased annual average temperatures and higher minimum winter temperatures coupled with an increase in atmospheric carbon dioxide and nitrogen are likely to have an impact on plant life. A longer growing season and potential faster rate of growth means that some bridge structures could be damaged, or their structural integrity compromised. This could be caused either by plants growing in stonework or invasive species such as Himalayan balsam undermining the stability of river banks. **[L]**

Human behaviour change

An increase to visitor and tourist numbers to the PDNP as a result of hotter, drier summers may increase wear and tear and damage from foot and particularly vehicular traffic. An increase in recreational off-road vehicle usage has the potential to cause increased damage to bridges which are on tracks or green lanes. **[L]**

It is also possible that there will be an increase in the building of hard flood defences in places as a result of increased winter precipitation. This can lead to channel water becoming higher before overtopping and therefore increasing hydraulic energy within the channel downstream of defences. **[L]**

What is the adaptive capacity of bridges? ***[Overall adaptive capacity rating: MODERATE]***

The construction of many of these features within the PDNP has proven to be fairly resistant to damage from erosion and weathering, and the survival of many of these bridges for hundreds of years demonstrates a good degree of inherent robustness of traditional building materials and techniques. However the tiny size of some bridges, particularly clapper bridges mean that a large storm event has the potential to be very detrimental. Once damaged, historic information is lost even if the structure itself can be repaired.

There is a fairly low number of packhorse bridges and even fewer clapper bridges in the PDNP and many span the same rivers. There is also limited diversity in construction techniques and materials, and many will be subject to similar stresses as a result of climate change.

Some funding is likely to be available for ongoing maintenance and the repair for damaged bridges – but this is dependent on location, ownership and the legal status of the route which the bridge carries. Those which are situated on public rights of way and highways are more likely to be maintained and inspected regularly. This increased level of oversight will also apply to those bridges which are listed. Funding from public sources or grants is more likely to be more easily available to bridges on land owned by organisations and charities such as the National Trust than individual private owners.

Key adaptation recommendations for clapper and packhorse bridges:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Slow the flow of water into rivers by ensuring landscape scale natural flood management in the uplands through blanket bog restoration, diversification of heather moorland and significantly increased woodland and scrub regeneration.
- Stabilise watercourse banks by encouraging tree and scrub growth adjacent to the channels where appropriate to reduce sedimentation and slow run-off entering.
- Encourage the designation of more structures by increasing knowledge base of these features.
- Engage with landowners and offer advice and funding streams for maintenance and repair of bridges.
- Control invasive species such as Himalayan balsam which can lead to the destabilisation of watercourse banks.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Conduct a survey to collect more detailed information about the current condition of these features and identify those individual structures which are most at risk.
- Select a sample of bridges which can be routinely monitored to track any deterioration in condition over time.

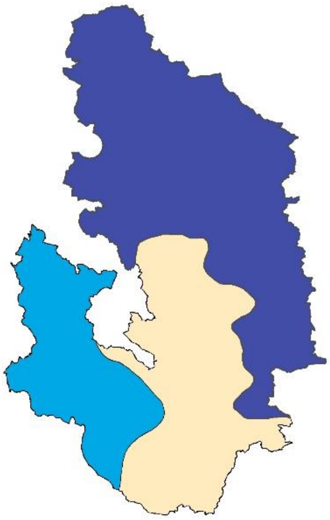
Country houses

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:

- Iconic country houses in parkland settings
- Stately homes and parkland
- Grand halls of the landed gentry



Special qualities:

- Characteristic settlements with strong communities and traditions
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

Country houses are often surrounded by parkland and designed landscapes. Some houses can be described as stately homes, which are impressive structures and sometimes include houses that are open to visitors. Grand halls of the landed gentry are another sub-category of country house. They were lived in historically by the landed gentry, a landowner social class.

The PDNP contains many iconic country houses in parkland settings, for example Chatsworth House, Haddon Hall, Thornbridge Hall, Lyme Park, Hassop Hall, Ashford Hall, Stanton Hall, Swythamley Hall and Tissington Hall. These properties are privately managed and owned, apart from Lyme Park which is primarily managed by National Trust and supported by the Stockport Corporation.

Country house infrastructures are historically significant and homes often hold many historical archives and artefacts, for example paintings, sculptures and pottery, and archives. Parkland landscapes have been designed over time; they hold great ecological importance as they have diverse and unique habitats supporting various species and great archaeological importance that reflects the landscape they were developed from as well as their own development over time. These grounds are often used for leisure and recreational purposes such as walks and sporting events, making them also culturally important. They hold significance for a wide range of people and are frequently used for educational visits by both adults and children.

How vulnerable are country houses?

Country houses and associated features in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a generally well managed current condition and a high adaptive capacity.

An increase in extreme climates, pests and diseases may pose a threat to species which define the character of the gardens at these homes and the historical archives contained within them. Changes to landscape may affect people’s desire to visit, decreasing the amount of resources available to protect the building and grounds from further harmful effects brought on by changes to climate. If they are well managed and resourced, country houses and their parkland settings have a high adaptive capacity.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Country houses are currently mainly well managed, however this is dependent on the resources available. They are affected by non-climate stressors, such as damage caused by visitors, but this has limited impact on their quality or function as it is often mitigated through maintenance. There are invasive species present which do impact the associated parkland, for example Rhododendron at Chatsworth House. Parkland at Lyme Park has already been damaged due to wildfire and parkland at some sites has already been lost entirely to development and agriculture.

In the summer of 2019 Lyme Park suffered from flooding. This saw some of the outbuildings damaged as well as the park and garden.

The majority of the country houses in the PDNP are listed and none are on Historic England’s Heritage at Risk Register.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Multiple climatic changes may lead to increased flooding, rainfall, frost and drought, which could all directly impact country houses and parklands.

Within country houses, items such as wallpaper, decorative surfaces and paintings rely on a stable climate for their maintenance and conservation. Electronic equipment which ensures the functionality of these buildings also relies on a stable climate to work correctly. Therefore items within country houses could be vulnerable to damage if extremes of temperature and rainfall become more frequent. All these items can also be easily lost entirely to frost fracture or flooding from extreme temperatures or precipitation. [**H**]

Old buildings which do not have adequate modern rainwater goods such as guttering and downpipes may not be able to cope with increases in rainfall, making them sensitive to damage. [**H**] Wooden buildings could be particularly susceptible to rot and historic leadwork could risk erosion from wetter conditions. [**H**] Drought may damage the structural stability of buildings. [**M**]

Increased rainfall leading to standing water conditions could also result in damage to parkland and gardens. An increase in storm events could damage old parkland trees. Conversely, reduced rainfall in summer could also negatively impact these landscaped gardens. If plant species are reliant on rainfall, the species composition of designed landscapes may be altered. [H]

Other structures, for example statues or fountains, can have footings made from certain geologies such as clay. These could dry under drought conditions and eventually collapse. Other historical structures may be sensitive to geological shrinking and swelling, for example grottos made from mortar. [H]

Invasive or other species interactions

Atmospheric pollution coupled with an increase in temperatures could mean that new flora, fauna and invasive or nuisance species spread into parklands, or that existing species spread further and become a nuisance. Higher levels of precipitation, flooding, storm events or humidity can also worsen the impact of this by encouraging the spread of diseases or pests. [H]

Some species in parklands, particularly trees, are sensitive to pathogens and therefore may be lost. One example of this is box blight fungus, which browns box leaves and causes branch dieback. Another is ash die back (see Slopes and Valleys with woodland). New species that are spreading into parklands also have the potential to bring unknown pests and diseases for example insect and fungal infestations. These insect and fungal infestations could then harm buildings and organic artefacts, meaning important historical objects could be damaged or lost. Infrastructure built with traditional materials may be more difficult to repair if materials are less easy to source. This could result in modification to the appearance of the designed landscapes and buildings, making them less desirable places to visit. [H]

Higher levels of precipitation and humidity could also increases incidences of mould and pests, such as common furniture beetles, weevils or silverfish. Within country houses, collections with cultural importance and interior furnishings could become vulnerable to damage or loss from mould or pests. [H]

An increase in flooding and storm events may mean that gardens and structures are left under water for prolonged periods of time. This could make them vulnerable to an increase in pests and diseases, leading to damage or loss of species or structures, potentially altering the landscape. [M]

Increased carbon dioxide and nitrogen levels from atmospheric pollution could result in an accelerated growth rate of invasive or nuisance species. Country houses and garden ornaments, for example fountains or statues, may be vulnerable to structural damage caused by this increased plant growth. These can include ivy, Japanese knotweed, algae, moss, and an overgrowth of trees and scrub. Parkland may be susceptible to bracken or Rhododendron overgrowth, which could result in more grounds maintenance being required and therefore higher running costs. [M]

Human behaviour change

Human behaviour changes as result of climate change have the potential to bring about various landscape and building structure alterations to country houses and parklands.

Hotter, drier summers may cause competition for water availability, changing how much is available to irrigate parks and gardens. It is possible that drought tolerant species will be more suited to the new environment and will outcompete drought sensitive species. This could change the aesthetics of the lawns and gardens within the parkland. [M]

Hotter, drier summers may also lead to an increase in visitor numbers which may damage parklands due to more foot traffic. More car parking spaces are likely to be needed to accommodate this increase in recreational use, expanding into parkland fields and damaging them. [L]

Severe or frequent flooding of parkland may make it unsuitable for grazing animals. In their absence this could allow scrub to develop where it was previously kept under control, changing the character of the parkland. Conversely, flooding of land elsewhere could increase stocking levels and result in over grazing by sheep or deer in parklands. [L]

A combination of climate change stressors may mean that the installation of insulation is required to improve thermal efficiency. This has the potential to decrease ventilation and increase the rotting of wood that makes up the frame of buildings and supports their slate roofs, leading to structural damage of the houses. [L]

Sedimentation or erosion

Erosion could result from more frequent and severe flooding and it could damage houses and parklands. Parkland and its associated buried floodplain archaeology and structures, for example bridges, may be damaged by erosion from high energy floods. [**H**] Fallen trees will further increase the risk of erosion and add to the damage of bridges and structures that are within the flood path. [**M**]

Other indirect climate change impacts

Hotter, drier summers could result in more frequent or severe wildfires. Parklands could be susceptible to wildfire damage, especially those with surroundings that are more prone to wildfire such as woodland or moorland. Building structures and materials could also suffer due to wildfire damage, as wooden buildings would be particularly susceptible. [**H**]

What is the adaptive capacity of country homes? ***[Overall adaptive capacity rating: HIGH]***

The preservation of these country houses is largely dependent on the availability of economic and technological resources. A large pool of finances and expertise are available to Chatsworth House and Lyme Park; Chatsworth House is part of the long-established Devonshire Estate and Lyme Park is managed by the National Trust. Privately managed properties, for example Haddon Hall or Thornbridge Hall, are generally assumed to have sufficient financial resources, however this cannot be fully relied on. Advice on climate change adaptations is available from Historic England. Grants for adaptation may also be available however privately owned or managed properties often have less access to grants than charities. This can make them less financially resilient and therefore less likely to install adaptation measures. [**H**]

Parklands often include a large variety of plant species and can include multiple different landscape types. This diversity makes them more resilient to future climate impacts. It is possible that they already include species or habitats that are more suited to future climate changes and will therefore continue to exist. Less diverse landscapes will be more vulnerable than their counterparts, so gardens can be designed with climate change stressors in mind to ensure they include a variety of suitable plant species. Trees are a defining aspect of parkland but there is less scope for selecting trees to plant that can cope with future climate stressors, therefore putting that aspect at greater risk. [**M**]

Country houses are often listed buildings which can provide some protection against inappropriate management techniques being used. Their condition is monitored so any problems arising can be addressed and the Heritage at Risk Register tracks some of the most vulnerable listed buildings and structures. It is more likely that action will be taken on listed buildings over non-listed buildings, and there is skill and information available to make adaptations and deal with damage to listed buildings from Historic England and PDNPA. [**H**]

Some parks are registered but this does not give them much additional protection unlike that provided for scheduled monuments and listed buildings. There is more formal protection for historic parklands within a Site of Special Scientific Interest, and there are Environmental Stewardship options available which provide funding to protect biodiversity and conserve natural resources. Additionally, the Gardens Trust is consulted about any planning permission applications on landscapes listed on Historic England's Register of Historic Parks and Gardens of Special Historic Interest. Historic England also need to be consulted on planning applications in areas with Grade I & II* listed structures and buildings. This can help protect these country houses and parklands. [**H**]

Restoration of country houses following damage from weather events is possible but likely to come at huge cost. Damaged gardens can be replanted but old mature trees and local plant species such as orchids are difficult to replace. Although any new climate change adaptations will reduce the risk of damage and loss, they may be difficult or costly to install or alter the aesthetics of a property. The National Trust has done work already elsewhere in the UK to increase the water capacity of downpipes so they can better handle large volumes of water in storm events. [**H**]

Key adaptation recommendations for country houses:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Have emergency plans in place for limiting damage during major climate events.
- Include country houses and their parklands in landscape scale flood risk management plans.
- Increase the resilience of the surrounding landscape to help create a buffer for these country houses and parklands. Form estate level plans for improved climate resilience, such as improving moorland condition to reduce flood risk.
- Consider collections and archives that could be at risk, and store those that are potentially vulnerable to damage from water, pests and overheating in places where these impacts will be smaller.
- Remedial work completed after damage has occurred should be appropriate for the specific building. See Historic England's 2010 (2015 edition) document 'Flooding and Historic Buildings' for examples.
- Undertake appropriate ecological and archaeological surveys to ensure that any plans are as fully informed as possible

Adapt infrastructure for future conditions

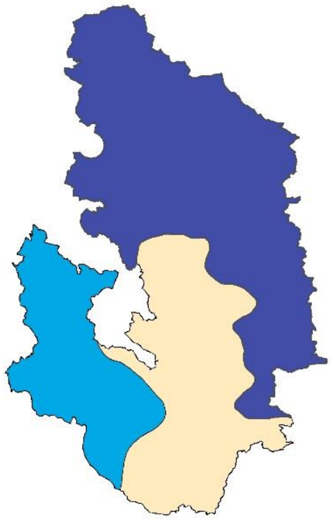
These recommendations are adaptations to physical infrastructure that should allow the features to better resist or recover from future climate change.

- Install rain harvesting and storage facilities at sites which are sensitive to drought. This is already in place at some properties.
- Keep abreast of new research into the performance of alternative materials for future climate adaptations.

Farmsteads

Overall vulnerability rating:

Very low	Low	**Moderate**	High	Very High



Feature(s) assessed:

- Diverse mix of farmsteads within villages and more isolated locations
- Small and medium sized farmsteads with a wide variety of layouts
- Late 18th and 19th century farmsteads

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry
- Characteristic settlements with strong communities and traditions

Feature description:

A farmstead is the term for a farm and its associated buildings. Traditional farm buildings are a familiar sight across all areas of the Peak District National Park. Mapping has revealed there are a total of at least 2,523 farmsteads in varying forms within the PDNP.

They are an important feature of the historic character of the landscape. The relationship of farmsteads to field patterns is also regarded as very important, especially to irregular enclosure, medieval strip fields and common lands.

See 'Field barns and outfarms' for more detail on these features. This assessment only focuses on farmsteads.

How vulnerable are farmsteads?

Farmsteads in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables but a positive current condition, and a high adaptive capacity.

Although there are farmsteads which are disused, derelict or have been changed in use, the position within the PDNP is better than the status nationally. Farmsteads are sensitive to changes in agriculture, and although some funding is available for their conservation it is very limited and their future is uncertain.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Farmsteads are under increasing threat. Changes to farming practices mean buildings become redundant which can lead to dereliction and loss – in turn changing the landscape and historic character of an area.

A very low proportion of farmsteads are designated heritage assets and the condition of many is in visible decline, particularly the more isolated buildings.

Uncertainty over the future of upland farming and the need to diversify means that there is increasing pressure for conversion. Buildings that fall out of use are more likely to become derelict, see also 'Field barns and outfarms' for more information on this.

Mapping has revealed that in some areas of the UK up to two thirds of farmsteads are no longer in agricultural use. The highest rates of survival in agricultural use are concentrated in the uplands and their fringe.

The PDNP has a very high survival rate of farmsteads – almost 90% of farmsteads have heritage potential because they have retained some or all of their historic form. There is a fairly diverse spread of locations as well as layouts and configurations with survival rates the highest in the White Peak and lowest in the Dark Peak. Distinct patterns of date, layout, type and survival of farmsteads within the Peak District can be related to the local geology, topography and landscape character areas.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Human behaviour change

Upland farmsteads are likely to be sensitive to changes in farming economics as a result of climate change. It may lead to buildings becoming redundant, refurbishment uneconomic and an increased demand for housing meaning greater pressure for conversions for residential use or holiday lets. **[H]**

Measures to mitigate climate change such as moves to improve and upgrade the thermal efficiency of buildings such as increasing insulation or installing solar panels on roofs may potentially have a negative impact. If ventilation is reduced as a result it may increase rot of wood and insect infestation, leading to deterioration in wooden framed buildings and slate roofs, and changing the character of the roof scape. Building regulations may also be at odds with the way historic stone buildings are designed so could create problems, especially for unlisted buildings. This in turn could see the loss of the historic significance and character of farmsteads within the PDNP. **[L]**

Changes in agricultural practices, farm diversification and amalgamation, and changes in settlement patterns, could have the result of gradually eroding the relationship between farmsteads and their landscape context. **[M]**

Direct impacts of climate change

These historic structures have the potential to be severely damaged by any increase in flooding, especially in locations within the landscape which are vulnerable to flooding and rain runoff. Structures could be damaged or weakened directly by hydraulic action and increase in flow of sediment or debris while repairs for repeated flooding may be uneconomic and lead to abandonment. A lack of understanding of how historic buildings are designed can lead to inappropriate interventions being taken, themselves creating further problems. **[L]**

Building materials are also sensitive to fluctuations of temperature causing increased thermal expansion and contraction of materials in particular wood, stone, metal, and paint. This can accelerate damage to building materials. **[M]**

Wet masonry and other building materials such as mortar are sensitive to frost, especially repeated freeze-thaw, and may be unable to cope with additional rainfall amounts and intensity. This may damage masonry, slates and other building materials. **[M]**

Sedimentation or erosion

In addition to wetter warmer weather having the potential to increase erosion through hydraulic action, periods of high temperatures and drought may also see the ground dry out and crack which could make building materials susceptible to damage compromising the overall long term robustness of structures. **[L]**

Invasive or other species interactions

Increased humidity could see a rise in mould growth in buildings, rot, and insect infestation, with any damage caused potentially needing intrusive renovation work. Changes in atmospheric conditions including increased carbon dioxide levels, coupled with wetter warmer winters may potentially see an increase in the growth in some plant species like Japanese knotweed or trees or shrubs, and therefore speeding up the rate of damage to structures. **[L]**

What is the adaptive capacity of farmsteads? ***[Overall adaptive capacity rating: HIGH]***

When compared to the rest of the UK, the PDNP has a very high survival rate of farmsteads with 2,523 mapped. This does not include approximately 2,600 field barns and outfarms which are assessed separately. These farmsteads are found across all areas and include a diverse spread of locations and a variety of layouts and configurations. Survival rates are highest in the White Peak and lowest in the Dark Peak. **[H]**

To date, traditional building materials and construction techniques have proved resilient to age – but the availability of economic resources to adapt and maintain farmsteads plays an important role in their survival. **[L]**

When it comes to making alterations to farmsteads, the planning system means many changes to building materials and adaptations to listed buildings can be controlled. However for unlisted buildings there is less control. In the PDNP as in the rest of the country a low proportion of farmsteads are designated heritage assets. **[M]**

Funding has been available through Countryside Stewardship schemes to help maintain or conserve farmsteads – however these resources are limited and their future uncertain. The highest level of financial support for landscape and heritage in England that includes the maintenance and weatherproofing of traditional farm buildings is the Countryside Stewardship and the Rural Development Plan for England. Such schemes have been particularly popular in the upland areas, where a high proportion of traditional farm buildings remain in agricultural use, but these areas are particularly sensitive to changes in environmental land management schemes. What will happen to these schemes in the future will depend on what the priorities are post-Brexit and any new regulations for rural development. **[M]**

Information and advice on making adaptations is readily available from various sources including the PDNPA. Whether change can be made however is less certain, as it also depends on the individual property owners, their building use and their economic situation - which are all factors in the likelihood of adaptations being sought. **[L]**

Key adaptation recommendations for farmsteads:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Use existing PDNPA farmsteads research to understand regional patterns and help inform decisions about change, taking advantage of advice from PDNPA officers – both farm advisors and buildings and archaeological specialists.
- Adapt traditional farm buildings where appropriate so they may still be used beneficially..
- See Peak District Farmsteads: Issues and Responses Report (2017), section 6.2 ‘Recommendations’ for further information.

Adaptations that could aid other features

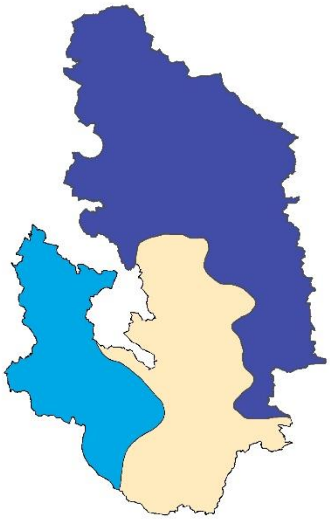
These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Consider keeping buildings standing for the benefits of wildlife.

Field barns and outfarms

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Field barns and hay lofts
- Isolated field barns
- Outfarms

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry
- Characteristic settlements with strong communities and traditions

Feature description:

Field barns are individual buildings that are not associated with a yard, that provide crop storage or animal shelter for example, whereas outfarms are a building or buildings associated with a yard and often some distance from the farmstead.

In all areas of the PDNP field barns can be found in many fields, in the corners, on the edge, or sometimes in the middle. These small stone buildings usually provided haylofts above and accommodation for livestock below.

There are over 2,600 field barn and outfarm sites in the PDNP. Of these, 13 have listed building status, four of which were built before 1700.

How vulnerable are field barns and outfarms?

Field barns and outfarms in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to a high sensitivity and exposure to climate change variables and a variable condition, but with a high adaptive capacity.

However, changes to farming practices have led to these buildings being subject to high rate of abandonment and loss. Changes to the economics of farming and farming practices due to climate change may drive modernisation of some historical farm buildings, altering the traditional character. Greater extremes of temperature may also be damaging to buildings exposed to the elements. Despite this the position in the PDNP is much better than the picture nationally assisted by the diverse location and layouts.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Outfarms and field barns have suffered high rates of loss. Due to their typically limited access and prominence in the landscape, changes to other forms of use can have a very high impact on their aesthetic and historical value and to the landscape as a whole.

Uncertainty over the future of upland farming, changing farming practices and the need to diversify mean that many upland farmsteads and field barns have become unused, or subject to another form of use. Unused buildings are more likely to fall into disrepair or dereliction.

Two-thirds of recorded examples in the PDNP are considered to be field barns comprising one or more detached buildings set within or on the edges of field. Of these, almost half retain some traditional farmstead character. Although many are marked as standing buildings on recent Ordnance Survey maps, it is likely that many of them suffer from some level of dereliction. By national standards this level of survival is high.

Just 13 of the over 2,600 field barn and outfarm sites recorded in the PDNP have listed building status. This very low level of designation is typical across England for this type of site and almost certainly represents under-designation, but further work is required to better understand the significance of the resource.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Human behaviour change

Upland farmsteads are likely to be very sensitive to changes in farming economics as a result of climate change. Buildings may become redundant, the refurbishment or maintenance of them may become uneconomic, or refurbishments may occur that causes the loss of historic character. Modern techniques may also be harmful to the way these buildings work as changes such as damp proofing, dry lining and impermeable insulation could potentially create problems within the buildings as they can no longer 'breathe'. [H]

Direct impacts of climate change

Building materials such as wood, stone, metal and paint are sensitive to fluctuations in temperature with an increase in expansion and contraction leading to an acceleration of attritional damage. [M]

Wet masonry and other building materials are sensitive to frost, especially repeated freeze-thaw, and may be unable to cope with additional rainfall frequency intensity. This could lead to damage of masonry, slates and other building materials. This may be made worse if there are inadequate rainwater goods or none at all. [M]

Winter flooding could see historic structures severely damaged or weakened by hydraulic action and increase in flow of sediment or debris. Repairs for repeated flooding may be uneconomic and lead to abandonment. [L]

Invasive or other species interactions

Increased annual average temperatures and wetter warmer winters could see buildings sensitive to structural damage from increased growth of some plant species such as Japanese knotweed, trees and shrubs, insect infestation, rot and fungi. This may accelerate the physical damage to building materials and cause structural problems with movement and collapse exacerbated by changes to the ground compromising building footings. [L]

Changes in humidity and wetter warmer winters could see an increase in mould growth in buildings, insect infestation and fungi. Damage caused in this way often needs intrusive renovation work. [L]

Sedimentation or erosion

The cracking of the ground in hot drought periods makes building materials susceptible to damage with the overall long term robustness of structures potentially compromised with damage to the fabric or solidity of walls. [L] In wetter weather traditional building materials can be damaged and degraded due to an increase in erosion by hydraulic action. [L]

What is the adaptive capacity of field barns and outfarms?

[Overall adaptive capacity rating: HIGH]

The Peak District has a high survival rate of field barns and outfarms. Their location is diverse as are the layouts and configurations found across the White, Dark and South West Peaks. [**VH**]

Countryside Stewardship options are available to restore, maintain or conserve traditional buildings as part of a pilot scheme however these sources are limited and their future is uncertain. [H]

Currently there is a very low level of designation, but there is potential to designate a greater proportion/the most important examples - but only if nationally significant. No field barns are currently on the national heritage at risk register. The PDNP has its own risk register for Grade II buildings and at least one barn in included within it. [H]

There is a good level of information about what assets exist, and the skills do exist to adapt and maintain buildings. However, there could be a lack of financial incentive to maintain or restore field barns as they are mostly redundant for modern farming. Adaptations may also be harmful to wider landscape and therefore contrary to planning policy. [H]

If funding is available field barns have the potential to be adapted to cope well with climate change however upgrades need to be appropriate to historic building materials or they risk causing problems, for example if the building cannot 'breathe'. Adaptations could also impact on the wider landscape. [M]

Key adaptation recommendations for field barns and outfarms:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- In order to halt large-scale dereliction and decay, some change in use is inevitable and work to enable quality conversions to economically viable uses, while maintaining the character as far as possible, should be encouraged where appropriate.
- Investigate alternative funding streams to support adaptation.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

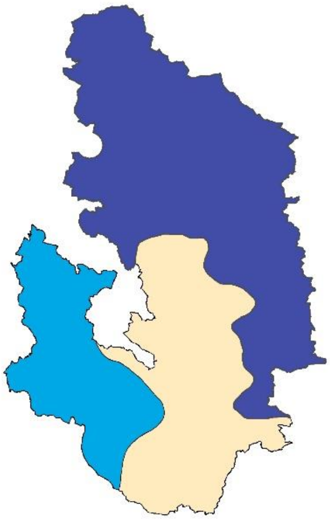
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Work to identify the most significant landscapes with field barns for enhanced maintenance through future environmental land management schemes.

Listed buildings

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Listed buildings

Special qualities:

- Characteristic settlements with strong communities and traditions

Feature description:

A listed building is one that has been designated as having special architectural or historic interest and is given extra protection in recognition of its importance to Britain's heritage.

The PDNP has some 2,900 listed buildings.

There are three grades of listing: Grade I for the finest buildings of most importance. Grade I listed buildings in the Peak District include Chatsworth House and Haddon Hall.

Grade II* for buildings of exceptional quality or containing special features. Ilam Hall and Eyam Hall are examples of Grade II* buildings within the National Park.

Grade II is for buildings of special interest. Around 94% of listed buildings come under this category.

How vulnerable are listed buildings?

Listed buildings in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a reasonable overall current condition, and a high adaptive capacity.

Only one property in the PDNP is currently on the national Heritage at Risk register that provides information on those under threat, however it only includes Grade I and II* buildings. The PDNPA holds its own list of buildings at risk, which includes 160 listed buildings (156 Grade II and 4 Grade II*). Climate change may increase damage to these buildings from extreme weather events such as flooding and storm damage. Greater fluctuations in temperature may also damage building structure as well as foundations. The designation of listed building status does provide some protection but the very nature of the properties means that changing them to make them more thermally efficient or modifying their rainwater goods for example, may be detrimental to what makes them special.

The buildings that are likely to be most vulnerable are those which are uninhabited, or those in private ownership that have limited resources available.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

There is currently only one listed building in the PDNP on Historic England's 'Heritage at Risk' register: Critchlow Monument, Sheen in the Staffordshire Moorlands which is recorded as being in "very bad" condition. However there are likely to be many Grade II listed buildings "at risk", but only Grade I and Grade II* are on the register. The PDNPA holds its own list of buildings at risk, which includes 160 listed buildings (156 Grade II and 4 Grade II*). The condition of these listed buildings may have changed however as some of the listings data is old.

There are stricter planning controls in place for listed buildings. While these help to safeguard buildings they can also make it more difficult for protective measures, such as flood proofing, to be put in place due to the more stringent planning requirements for alterations.

There is a pressure to increase the thermal efficiency of buildings, and develop alternative power sources such as solar energy and ground source heat, whilst retaining historical features. However, such changes could be detrimental to the function and aesthetics of the buildings and the townscapes and landscapes beyond them, and therefore creative approaches are needed.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

There are many ways in which climate change could impact listed buildings as different historic structures are built to different standards and using differing construction techniques. An increase in the frequency and severity of winter flooding could in some cases potentially see severe damage caused, however in some cases traditional structures may be more resilient than modern buildings. Hydraulic action and the increase of flow of sediment or debris may damage or weaken structures. Repeated flooding and the need for repairs may make the building difficult or very expensive to insure. Extreme weather conditions could lead to irreversible damage, or even collapse. **[M]**

Buildings are sensitive to geological shrink and swell. Hotter drier summers could see the drying out of certain geologies such as clay which can increase subsidence affecting these historic structures. Wetter warmer winters may have an impact due to poor or inadequate rainwater goods including historic guttering and downpipes, while wet masonry is sensitive to freeze-thaw. It is not only the exterior of these buildings that could suffer, as damp may also be an issue for the interiors and contents of the building. These changes could also be exacerbated by maintenance and repair issues. Damage may ultimately lead to the loss of historic structures due to changes in structural integrity leading to movement or collapse. **[H]**

Building materials such as lead and leadlight windows are sensitive to fluctuations in temperature with an increase in thermal expansion and contraction of materials such as wood, stone, metal and paint. This could then accelerate attritional damage of building materials leading to issues over repairs and maintenance. **[M]**

Human behaviour change

Listed buildings may also be sensitive to inappropriate post-flood remedial works for example buildings may be damaged from repeated rapid artificial drying while inappropriate works by contractors may see unnecessary disposal of important fixtures and fittings. **[M]**

The move to upgrade the thermal efficiency of buildings by increasing insulation may also lead to a decrease in ventilation. Older buildings may suffer from increased rot with deterioration in wooden framed buildings and slate roofs supported by wooden battens. There may also be pressure to embrace renewable energy such as solar, air, water and ground source heat. **[L]**

A result of hotter summers could be an increase in the number of people visiting the PDNP. Buildings may be susceptible to damage from crime, vandalism, and accidental fire. This can cause accelerated damage to some buildings as an accidental fire may not only result in direct damage, but also lead to water damage from the process of extinguishing it. **[M]**

Sedimentation or erosion

Cracking of the ground caused by hot drought periods makes traditional building materials susceptible to damage. If they increase in frequency the overall long term robustness of structures may be compromised. Any impact on the foundations or any movement in the structure could be detrimental for listed buildings and costly for owners to repair. **[M]**

If winters are wetter traditional building materials could see an increase in erosion by hydraulic action with stone for example damaged and degraded. Where replacement stone may be required like-for-like replacement may be more challenging. **[M]**

Invasive or other species interactions

More humid conditions may see an increase in the growth of mould, rot and insect infestation. This may cause damage particularly to internal structures and fittings. **[M]**

Increased annual averages and wetter warmer winters could see buildings suffering structural damage from increased growth of some plant species like Japanese knotweed, trees and shrubs, insect infestation, rot and fungi. This could accelerate physical damage to building materials and cause structural problems with movement and collapse exacerbated by changes to the building foundations. **[L]**

What is the adaptive capacity of listed buildings? ***[Overall adaptive capacity rating: HIGH]***

Across the whole of the PDNP there is a very diverse set of historic assets and while some will be more vulnerable than others, listed buildings will not be lost entirely. **[H]** Many historic structures are inherently resilient and can recover well from extreme events, such as flooding, if treated appropriately. **[H]**

Most listed buildings will be insured, offering some protection if they suffer damage. Grants may be available from organisations such as Historic England and the National Lottery Heritage Fund to improve the resilience of buildings by installing adaptations where appropriate on Grade I and Grade II* buildings although funding is limited and often targeted to buildings at risk. Information on what type of grants may be available can be found via Heritage Alliance 'Heritage Funding Directory', however grants are less likely to be available to private owners than for example to a registered charity. No grants are available for Grade II listed buildings, and the grants that are available are not always compatible with conservation and enhancement of listed buildings. **[H]**

Some protection from inappropriate adaptive or remedial work is provided if a building has been listed. However, this can only work if there is a good system of monitoring condition in place so that problems are noted and action can be taken and owners are aware of the requirements that come with listed status. The Heritage at Risk register is a reasonably robust way of tracking some of the most vulnerable buildings, but there are in reality likely to be many more buildings which are at risk. The condition of buildings is only usually monitored from the outside. There is a raft of advice, guidance and legislation to respond to and manage listed buildings. **[H]**

A good level of information and skill is available to make appropriate adaptations and to deal with extreme events damaging listed buildings, both during and after damage occurring. Advice is available from Historic England and PDNPA. Having listed status means buildings have a better chance of appropriate action being taken than other building types. **[H]**

Key adaptation recommendations for listed buildings:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Remedial work completed after damage has occurred should be appropriate for the specific building. See the Historic England 2010 (2015 edition) document 'Flooding and Historic Buildings' for examples.
- Provide good information on appropriate materials, and encourage building owners to carry out timely maintenance and repairs.
- Create/maintain strong partnerships with external organisations to highlight materials sourcing issues, and ensure steady supply of appropriate materials (e.g. Historic England, minerals operators, architects, tradespeople).
- Nurture collaborative networks to build capacity for monitoring (e.g. local interest groups).

Adapt infrastructure for future conditions

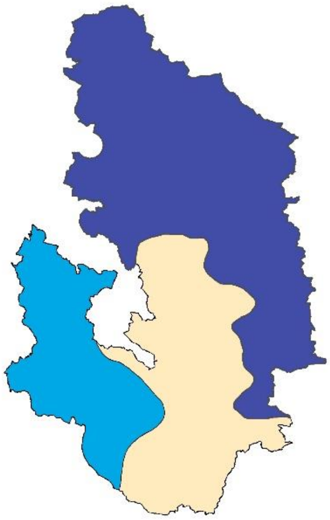
These recommendations are adaptations to physical infrastructure that should allow the features to better resist or recover from future climate change.

- Installation of appropriate adaptive measures should be encouraged and regular condition inspections should be carried out.
- Keep abreast of new research into the performance of alternative materials for future climate adaptations.
- Encourage the use and benefits of traditional materials. Review building design with the impacts of climate change in mind.

Paths, tracks and trails

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Paths, tracks and trails
- Activities that improve physical health such as walking, cycling and adventure sports
- Dense rights of way network

Special qualities:

- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description: A series of paths, tracks and trails criss-cross the PDNP. They are found in the White Peak, Dark Peak and South West Peak.

People use these routes for a range of recreational activities and sports including hiking, cycling, horse-riding and driving.

In the PDNP there are 2,136 km of footpaths, 294 km of bridleways, 30 km of byways and a further 546 km of unclassified roads, sometimes referred to as green lanes.

There are four recreational trails managed by the PDNPA. They are the High Peak, Monsal, Thornhill and Tissington trails and they run for around 55 km in total. Several long distance routes cross the PDNP such as the Trans-Pennine Trail and the Pennine Way which starts in Edale.

To increase accessibility regardless of mobility restrictions there are now Miles without Stiles routes (32 km in 2018), where tracks and paths have been adapted to be accessible for all.

How vulnerable are paths, tracks and trails?

Paths, tracks and trails in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varying current condition, and a moderate adaptive capacity.

The condition of routes often depends on their popularity with those heavily used becoming worn quite quickly and needing more maintenance and upkeep. Routes are sensitive to severe weather including wind and rain that can cause erosion. Increases in this damage due to climate change pose a significant risk to their condition. Damage to the physical infrastructure such as bridges may also occur. However, both the constituent highway authorities and PDNPA work to maintain routes and while funding is limited, campaigns have successfully raised money for specific work such as the Great Ridge.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

The condition of paths, tracks and trails across the PDNP is mixed, and difficult to accurately assess overall because conditions in specific areas can change quite rapidly. Because they are used for a range of recreational activities, the most popular routes can often become worn quickly. The weather can cause damage to their surfaces, for example heavy rain can very quickly render a path impassable.

Those areas of heavy usage require more maintenance and upkeep depending on what activity they are used for and the nature of the path, track or trail. Most paths also experience some level of vegetation growth, with some areas requiring maintenance particularly at the edge of tracks.

The scale and cost of repairs has seen recent fundraising initiatives launched, including the Mend Our Mountains campaign.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Sedimentation or erosion

Some path surfaces, slopes and cuttings are sensitive to erosion. An increase in winter precipitation is likely to increase erosion rates, and this could make some paths unusable. This would also increase the health and safety risk for users. Winter storms and summer droughts could cause the potential loss of bridges or paths in some areas, requiring replacement or rebuilding to ensure they remain usable. **[H]**

Wetter winters may mean that paths and associated structures such as bridges could suffer more severe impacts from freeze-thaw events. Conversely, it may also be there are fewer freeze-thaw events due to warmer winters overall, which could see less damage caused. **[L]**

Direct impacts of climate change

Trails and trail structures such as bridges are sensitive to storm events. As well as direct damage to the features themselves, there may also be an increased risk of tree failure and rock fall. This potentially poses an increased health and safety risk for people using the trails. The flooding of path surfaces or obstructions caused by fallen trees or rocks may temporarily block paths, or make them inaccessible and could lead to increased costs for maintenance and for durability. **[M]**

Trail structures may also be sensitive to air pollution with bridges or cuttings damaged, for example stone may be damaged by acid rain leading to potential aesthetic impairment of the feature. **[M]**

Trail tunnels are sensitive to increased rainfall and could be damaged by flooding leading to paths being closed to visitors in some places. **[M]**

Other indirect climate change impacts

An increased frequency of summer drought and decreased rainfall increases the risk of wildfire. There is increased likelihood that some paths, tracks or trails may be closed to prevent fires starting, reducing the wellbeing benefits provided. **[M]**

Human behaviour change

Hotter, drier summers may result in an increase in the number of people visiting the PDNP, leading to a greater footfall on routes which could increase the risk of erosion and also wildfire ignition. There is also a potential risk to places for quiet reflection due to any significant rise in visitor numbers. **[L]**

Invasive or other species interactions

Warmer, wetter winters and hotter summers could lead to longer growing seasons and impact routes sensitive to vegetation growth, particularly narrow paths. They may become overgrown and difficult to use and therefore may pose an increase safety risk to visitors and require an increase in maintenance in some areas. **[L]**

What is the adaptive capacity of paths, tracks and trails?

[Overall adaptive capacity rating: MODERATE]

The various highways authorities which cover the PDNP, and the PDNPA restore and maintain routes, particularly rights of way. However, many trail structures are substantial in size (for example tunnels and viaducts) and will continue to require large amounts of maintenance and investment. **[M]**

Fundraising efforts have and are being used for right of way restoration. Limited funding is available especially for projects of some magnitude, so there are resource implications. **[M]**

Closures of individual parts of the route network could impact its overall connectivity for different users. However, the network is diverse with a variety of different surface types, and sometimes alternative paths can naturally be created. This means the overall functionality of the path network may not be lost even if parts are degraded, and in the case of specific paths, tracks or trails alternatives may be able to be purposefully created or upgraded. **[L]**

Many techniques for path restoration currently exist and there are many skilled contractors available to carry out adaptations where funding is available. **[L]**

Key adaptation recommendations for paths, tracks and trails:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Monitor condition of key paths, tracks and trails and reassess vulnerability on an ongoing basis.
- Invest time in developing further crowd-sourced funding for adaptation of paths, tracks and trails, fostering a sense of ownership among user groups.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Assess which specific stretches of path, track or trail are likely to be most vulnerable to climate change.
- Maintain and upgrade those areas subject to heavy usage or those likely to be most vulnerable. Understand the heritage significance of trails to factor this into decision making.

5.3. Communities

Communities

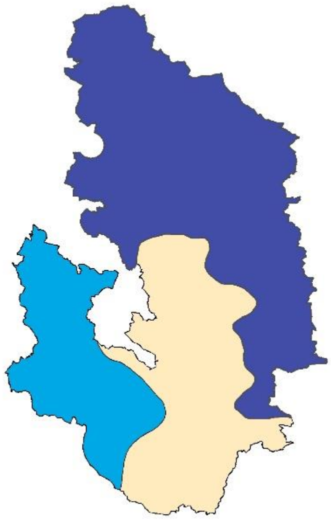
	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Local events	High	High	**Moderate**	103
Open access land and public access	Moderate	Moderate	**Moderate**	107
Transport links into the PDNP	Moderate	High	**Low**	112

Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

Local events

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Local events

Special qualities:

- Characteristic settlements with strong communities and traditions
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

The towns and villages across the PDNP hold a wide range of events throughout the year that are attended by local people as well as visitors from the surrounding communities and further afield. Many have origins dating back over a hundred years, while others are so ancient that their origin is not fully known.

Many events are specific to individual communities. Examples include Castleton Garland Day and Winster Pancake Run. These types of events are often tied to a particular date in the year.

Well dressings are popular and are held on various dates between May and September and feature intricate designs created by pressing natural materials into clay boards. One of the earliest and well known is held in Tissington.

The wide range of events include carnivals, fell races, village fetes, sheep dog trials, and country shows are held in various locations including Hope, Chatsworth and the Manifold Valley.

How vulnerable are local events?

Local events in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively stable current condition, and with a high adaptive capacity.

Changes in the climate could have a significant impact on local events particularly those that rely on the weather or are tied to a specific date. The majority are run by volunteers and depend upon funds raised one year to finance the following year's event. A series of poor years could mean the event is lost entirely.

In recent years a small number of events have been lost, however local events do have a high adaptive capacity as demonstrated by the Bakewell Show which changed its date and format in 2019 due to wet weather.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Throughout the PDNP a vast range of events takes place throughout the course of the year.

They vary from those that are small community orientated events such as village fetes, to those that attract visitors from far and wide such as the country shows.

Many events are reliant on the weather and poor conditions such as successive wet summers can have a negative impact and contribute to events suffering financial losses.

A number have been lost in recent years such as the Hartington Steam Rally, while Bakewell Show was not held at all in 2018 and was scaled back in 2019 due to damage caused to the showground and revenue being lost.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate change has the potential to have a significant impact on local events. The number of people who attend can often depend upon the weather, so hotter drier summers could see a rise in visitor numbers and those taking part – potentially diminishing quiet reflection areas at peak times. **[H]**

Higher visitor numbers may also put pressure on access, and lead to a greater demand for water and shade particularly at sports events and shows that feature animals. Higher maximum summer temperatures would also increase the risk of heat stress for people and animals at such events. **[H]**

Climate change may lead to changes in the timing of seasonal events such as lambing or calving and the flowering of certain plants, which could lead to changes in event dates for example country shows or well dressing festivals. **[H]** An increase in the frequency and severity of storms and extreme weather could see the loss of vegetables and flowers for markets and the interruption or cancellation of such events. **[M]**

Increased rainfall after long dry periods could lead to greater fluctuations in water levels (in rivers and ponds) while access routes and infrastructure may be sensitive to heavy rain events because of flooding or erosion. Matlock Bath Illuminations depends on water levels in the River Derwent while well dressing clay is often soaked in local water bodies so traditional methods or timings may need to be altered. **[H]**

Human behaviour change

Visitor numbers are sensitive to weather conditions. An extended warm season could result in an alteration in the timing of peak visitor numbers. Some events may be held earlier or later in the year to avoid the hot mid-summer. There may also be an opportunity to create new events that could be spread throughout the warmer months and in more locations. **[H]**

Sedimentation or erosion

Paths and access routes may be vulnerable to erosion by increased rainfall after long dry periods. This could affect access to events but also see organised events taking place over poor ground conditions with routes widened by participants trying to avoid the worst affected sections leading to further erosion. **[M]**

Any impacts on infrastructure such as blocked drains, gullies on roads, damage to roads and rail routes could disrupt or limit access to events. **[H]** Paths may also be damaged or eroded not only leading to an increase in the maintenance required but also a need to change access to events or course routes for sporting events such as fell running. **[M]**

Nutrient changes or environmental contamination

A rise in visitor numbers attending events as a result of hotter, drier summers could see a decrease in air quality arising from traffic pollution. This may be offset by an increase in electric vehicles or use of public transport as a climate change mitigation response. **[M]**

Invasive or other species interactions

Increased temperatures will likely lead to an increase in the survival of pests and pathogens. As events can bring together people from all over the country there may be an increased risk from outbreaks or spread of pests and diseases. [**M**]

Changes in atmospheric composition such as increased carbon dioxide levels coupled with higher annual average temperatures could see some plants grow more vigorously. Paths would be more likely to become overgrown and un-usable and there may be a need for increased maintenance or the use of alternative routes for certain events. **[L]**

What is the adaptive capacity of local events? ***[Overall adaptive capacity rating: HIGH]***

Many local events will have the capacity to recover or be adapted to climate changes with the support of those who organise them. It may be the timings of some events can be altered to different times of the years, for example. Some events may be less flexible if they have long traditions of being on the same day every year, and as a result these are likely to be the most vulnerable. **[M]**

Across the PDNP a diverse range of event types are held in diverse locations. The majority of areas and events will remain open even if some are closed or abandoned, and despite such changes an overall 'programme of events' is almost certain to continue. **[H]**

The range of groups and organisations are as varied as the number of local events they organise. Large events such the Royal Horticultural Society (RHS) Chatsworth Flower Show have strong economic resources allowing them to respond and adapt, while smaller private events which are less well-financed are likely to have less adaptive capacity. **[M]**

Event management skill and information is an important resource in determining adaptive capacity. For example, organisers of many larger events typically have a risk assessment in place looking at adverse weather and using forecasts to determine if an event goes ahead, is postponed, or cancelled. In this respect smaller events run by local volunteers without such processes in place may be less resilient in the long term. **[M]**

In terms of maintaining public access to events, maintenance of main roads is carried out by Highways England (A628 only in the PDNP) and local highway authorities, with the latter also dealing with repairs to public rights of way and producing Rights of Way Improvement Plans alongside the

PDNPA. Many organisations including water companies, National Trust, Moors for the Future Partnership and the Forestry Commission work to restore habitats across large upland areas, increasing resilience to climate change through Natural Flood Management of water catchments. **[M]**

Key adaptation recommendations for local events:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Provide advice and support to help event organisers of locally run, volunteer led and traditional events to adapt to climate change and implement more robust processes.
- Assess the value of events and traditions to the PDNP economy and consider whether financial support and grants would be feasible to support the most vulnerable traditions.
- Adapt to increased visitor numbers as a result of hotter, drier summers. Encourage public transport usage for larger events and encourage the provision of extra buses and trains, and low carbon transport, to reduce congestion and improve air quality.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Create visitor management plans for peak times and honeypot areas. Identify areas that are vulnerable to crowding and influence behavioural changes to spread out visitor impact
- Manage visitor numbers at high-risk sites and events.

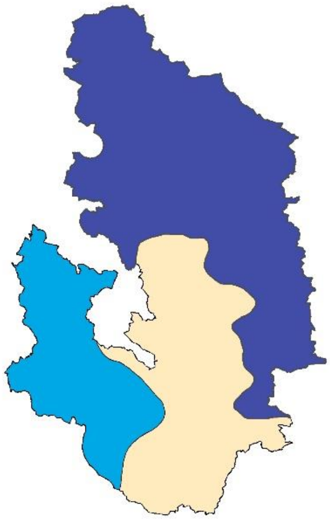
Open access land and public access

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:

- Open access land
- Public access
- Access and rights of way routes



Special qualities:

- Undeveloped places of tranquillity and dark night skies within reach of millions
- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

Open access land, access routes, and public rights of way can be found across all areas of the PDNP. A third of the PDNP is open access land. There are 2,460 km of public rights of way, 200 concession routes, and 20 promoted accessible routes. There are also 546 km of unclassified roads.

The Countryside and Rights of Way Act 2000 (CROW Act) gave the public right of access to land mapped as 'open country' (mountain, moor, heath and down) or registered common land, for activities such as walking, running, watching wildlife and climbing. There are certain restrictions for activities including horse riding and cycling which are usually prohibited unless the landowner allows them, if public bridleways or byways cross the land, or there are local traditions providing rights of access.

On access land, there is a right to close the land for conservation reasons, land management, public safety, or at times of exceptional fire risk.

Some land uses, such as gardens, buildings and working quarries, are excluded from the 'right to roam' and public rights of ways must be used to cross these areas.

The PDNP features three long-distance trails on public rights of way: The Pennine Way, Pennine Bridleway and Trans Pennine Trail. There are also five 'trails' that run along ex-railway lines: the Manifold Trail (also known as Manifold Way), the High Peak and Tissington which are public bridleways, and Monsal and Thornhill which are concessionary paths.

How vulnerable is open access land and public access?

Open access land and public access in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varied current condition, and with moderate adaptive capacity.

Erosion could be one of the key potential impacts of climate change, as many paths are susceptible to extreme weather events and the most popular routes that are heavily used already suffer from erosion.

There is limited funding available particularly for larger projects. However new initiatives for fundraising such as the 'Mend our Mountains' campaign are having a positive impact for specific routes.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

The heavy use of some of the most popular routes has already caused major erosion, especially in moorland areas where damage is exacerbated by degraded peat, high rainfall and wind. Historic erosion of moorland due to wildfire, pollution, drainage and overgrazing has meant some paths have become very inaccessible.

One major route that has been subject to erosion control and re-vegetation measures during recent years is the Pennine Way National Trail, which starts at Edale. This has seen paving introduced on some sections, which has reduced further erosion and has allowed the re-vegetation of previously eroded peat.

Access land and public rights of way are used by a considerable number of people (residents and visitors) engaged in a wide variety of activities such as walking, cycling and horse riding. This puts pressure on the existing infrastructure and the sense of tranquillity and remoteness to be found in the PDNP. Dovedale in the White Peak can become extremely congested at peak times and such 'honeypot' locations are under the greatest pressure.

Due to limited resources, new ways of fundraising are being explored. For example, there are severely eroded routes currently being addressed by the 'Mend our Mountains' project for The Great Ridge and Cut Gate.

What are the potential impacts of climate change? ***[Overall potential impact rating:* MODERATE*]***

Sedimentation or erosion

Climate change could have a significant impact on open access land and public access.

Paths, tracks, trails and bridleways are sensitive to erosion by wind and rain. Any increase in extreme weather such as the frequency and severity of storms, flooding and drought could lead to the potential loss of bridges or paths in some areas, requiring replacement or rebuilding. Paths may also be temporarily blocked or inaccessible leading to higher maintenance costs. **[H]**

Prolonged winter rainfall could see an increase in erosion particularly on softer or unsurfaced routes, and subsidence could become a problem in some areas. This could lead to some paths becoming unusable while any difficulties involving bridges could cause prolonged route closure. **[H]**

Conversely warmer winters could see less damage to paths as a result of fewer freeze-thaw events. **[M]**

Human behaviour change

Any increase in the frequency and severity of storms and droughts could see a rise in the risk to public safety as well as maintenance and legal costs. There may be an increase in pre-emptive closures of access due to high fire risk for example, while infrastructure such as the Monsal Trail Tunnels may need to close at short notice if any emergency repairs are needed, or a public safety risk is predicted. **[M]**

Hotter, drier summers may lead to an increase in visitor numbers seeking access to the outdoors. An increased risk of wildfire could see the pre-emptive closure of access land by land managers. A higher volume of visitors may lead to increased foot traffic and widening of paths as eroded or boggy patches are avoided. This would cause damage to environmentally sensitive areas. Maintenance costs of infrastructure such as paths, interpretation panels and furniture could rise. If the volume of people increases even further in current honeypots, the PDNP may lose its appeal as a place of tranquillity. There could also be an increase in the workload of PDNPA staff such as rangers. **[L]**

Increased demand for climate change mitigation such as wind farms, solar farms and biofuel crops could see open access land subject to land use changes. Although these scenarios currently appear unlikely due to the planning system, they are worth considering as planning legislation is unlikely to remain static over the next century and indeed radical reforms are quite possible. **[L]**

Direct impacts of climate change

Footpaths, tracks and bridleways may become obstructed by fallen trees more regularly or suffer flooding if the frequency and severity of storms increases. Paths may be temporarily blocked or inaccessible, and there could be an increased cost of maintenance. **[L]**

Invasive or other species interactions

Most paths experience some level of vegetation growth. Atmospheric changes such as increased carbon dioxide and nitrogen levels could lead to some plants growing more vigorously, which may become an issue on narrow paths if they were to become overgrown and unusable. Any increase in annual average temperatures could lead to a longer growing season, which could also impact paths sensitive to vegetation growth. This may lead to paths, tracks and trails becoming overgrown and more difficult to use requiring an increase in maintenance in some areas. **[L]**

Other indirect climate change impacts

The risk of wildfire ignition increases as visitor numbers rise during drier summers and drought periods, especially at heather or grass moorland sites. Wildfires may cause extensive damage to sensitive areas and wildlife, lead to increased costs and public safety risk. Paths or access land may be closed during exceptional fire risk. **[L]**

What is the adaptive capacity of open Access land and public access? ***[Overall adaptive capacity rating:*** **MODERATE*]***

There are a variety of different surface types, widths, and extensive network of rights of way across all regions of the PDNP. The majority of areas will remain open even if some are closed during any given period. Sometimes alternative paths can naturally be created or an alternative route can be purposefully created so the functionality of a path may not be lost. Harder, more permanent surfaces are more resistant to storm events but can also increase the rate of run off. **[L]**

Highway Authorities and PDNPA restore and maintain rights of way. There is limited funding available for maintenance and repair of routes - especially for projects of magnitude. There are also PDNPA resource implications of fundraising for right of way restoration, for example the 'Mend our Mountains' campaign. Catastrophic events can bring in funding but little is usually done pre-emptively. **[M]**

Large organisations such as water companies, National Trust, Moors for the Future Partnership, and Forestry Commission are currently restoring habitats on large areas of moorland access land. This should increase resilience to climate change and allow it to stay open. Blanket bog restoration that is ongoing at a landscape scale will make access land on moorland more resilient. **[L]**

Currently there are lots of techniques being employed for path and habitat restoration and many contractors with the necessary skills to implement them. **[L]**

Key adaptation recommendations for open access land and public access:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Monitor condition of key paths, tracks and trails and reassess vulnerability on an ongoing basis.
- Provide funding for resilience planning. Take a proactive approach to improve path structure in a smaller way rather than waiting for a damaging event before acting.
- Invest in and encourage natural flood management across the PDNP including the restoration of upland habitats and the regeneration of large areas of woodland and scrub.
- Invest time in developing further crowd-sourced funding for adaptation of paths, tracks and trails, fostering a sense of ownership among user groups.
- Work to reduce the risk of wildfire ignition.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

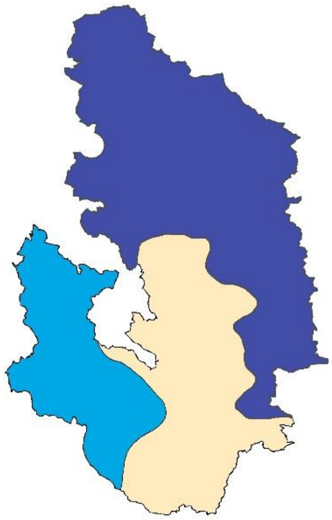
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Maintain and upgrade those areas subject to heavy usage or those likely to be most vulnerable.
- Create visitor management plans for peak times and honeypot areas. Identify areas that are vulnerable to crowding and influence behavioural changes to spread out visitor impact
- Continue to foster partnerships to help manage the impacts affecting open access land.

Transport links into the PDNP

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Transport links into the PDNP
- Transport routes
- Direct access routes from urban surroundings

Special qualities:

- Undeveloped places of tranquillity and dark night skies within reach of millions
- Characteristic settlements with strong communities and traditions
- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape

Feature description:

The PDNP is one of the most accessible national parks in the world. Over 15 million people live within 40 miles or an hour's drive away. Millions of vehicles travel in and around the area every year.

The A628 Woodhead Pass is the only trunk road to cross the PDNP and is the responsibility of Highways England. 'A' roads that run through the park, crossing several local authority boundaries, include the A53, A537 and A57, which come under the jurisdiction of the relevant local highway authority in each area.

Smaller villages are predominately served by 'B' roads, however Bakewell, the only town within the PDNP, is served by the A6 and A619.

Rail and bus services provide access to much of the PDNP. Neighbouring cities and major towns include Sheffield, Manchester, Derby, Chesterfield and Macclesfield. All have regular intercity rail services from destinations across the country. Only the Hope Valley Line between Manchester and Sheffield actually passes through the PDNP, stopping at stations in Grindleford, Hathersage, Bamford, Hope and Edale. Regular bus links connect towns lying beyond the boundary with towns lying within the PDNP itself.

How vulnerable are transport links into the PDNP?

Transport links into the PDNP have been rated 'low' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a reasonable current condition, and high adaptive capacity.

Transport links in the PDNP are generally in good condition, but subject to some pressures including weather. Major routes are already susceptible to adverse weather with snowfall often leading to the closure of the high level routes. Increases in extreme weather conditions are therefore a key potential impact of climate change on the transport infrastructure.

However, research is now being carried out by organisations responsible for transport infrastructure to look at what measures can be undertaken to increase resilience to the potential impacts of climate change.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: HIGH

Current condition:

Roads and rail in the PDNP have periodically been closed by flooding. Roads at higher altitude such as A57 Snake Pass, A628 Woodhead Pass, A537 Cat & Fiddle, A6024 Holme Moss, A53 Axe Edge are regularly closed by winter snow. During fine weather and on weekends the honeypot locations such as Bakewell see significant road congestion.

Erosion is having an impact on a number of roads. The A57 Snake Pass has a similar geology to the old Mam Tor road and has suffered a number of landslips over the last few years through drought, freeze-thaw and flood. The A54 and A619 have also seen undercutting erosion of retaining walls.

The cities surrounding the PDNP have intercity rail services. However only the Hope Valley Line between Manchester and Sheffield has a stopping service within the PDNP (currently operated by Northern Trains).

Three lines stop just outside the boundary: Derwent Valley Line from Derby to Matlock (East Midlands Railway), Manchester to Glossop (Northern Trains) and Manchester to Buxton (Northern Trains). From these towns bus services are available into the PDNP.

A fourth line from Manchester runs to Huddersfield (TransPennine Express), with stations at Greenfield and Marsden.

It is possible to access most parts of the PDNP by bus. While some services run daily or even hourly, there are others that are only run at weekends or peak holiday periods.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Direct impacts of climate change

Transport routes are susceptible to changes in the weather. Increased summer temperatures are likely to see tarmac melt and rails expand and buckle. Smaller roads may be particularly affected as they are built to lower specification than motorways and trunk roads, although they do carry lower levels of traffic. If road surfaces become brittle they may crack allowing water ingress, resulting in potholes and the rapid deterioration of the surface. This may lead to some routes being closed at peak times, delays and an increase in infrastructure maintenance costs. There may also be an increased risk of accidents. Hot weather can also affect mechanical and electrical systems affecting vehicles as well as road and infrastructure. These issues have the potential to have an impact on the PDNP economy and sustainability of businesses. **[VH]**

Storm events could see routes blocked by fallen trees and flooding from rivers or caused by heavy rainfall. Routes may be temporarily blocked or inaccessible (especially those in floodplains) and incur an increased cost of maintenance. **[M]**

Sedimentation or erosion

It is likely to be extreme winter and summer events that have the biggest impacts. There could be an increase in road, footpath and track erosion rates. Drier summers may lead to cracking of the ground which makes foundations of bridges susceptible to damage and subsidence. There may also be a rise in disruption to earthworks along transport and flood defence corridors, including: shrink and swell around pipework; landslips; undercutting; and bridge scour. Underlying geology makes some areas more likely to experience land slips as in the case of the old Mam Tor road. A period of drought and severe winters led to the final collapse and abandonment of the road. **[H]**

Roads, railways, paths, tracks and trails are sensitive to erosion by wind and rain. Any increase in frequency and severity of storms could also see higher river flows damaging road and rail bridges through debris impact and the erosion of foundations. Modern bridges have benefitted from improved design and better understanding of weather, but older masonry arch bridges remain vulnerable. The potential loss of bridges or key routes may mean they need to be rebuilt or replaced. Routes could be temporarily blocked or inaccessible and there may be increased cost of maintenance. This could impact the PDNP economy and sustainability of businesses. **[H]**

Warmer winters could have a positive impact by reducing damage caused by freeze-thaw. Disruption related to cold, snow and ice could decrease and could bring a positive impact to the PDNP economy and sustainability of businesses. However if warmer winters are also wetter there could be increased issues with flooding and erosion, if water leads to the undercutting of retaining walls for example. **[M]**

Human behaviour change

Hotter, drier summers may see an increase in visitor numbers from cities. Paths, tracks and trails are sensitive to increased foot traffic and there may also be an increase in wildfire ignition sources. Any increase in traffic could see roads becoming congested. This may lead to increased maintenance costs of transport infrastructure and the loss of appeal of the PDNP as a place of tranquillity, with visitor hotspots becoming even busier. **[H]**

A rise in extreme weather could see increased public safety risks, maintenance and legal costs. Access to public rights of way may be restricted by flooding and storm damage or emergency repairs. Flood events often leave sediment on the road surface and this could have an impact. A study has found a link between extreme weather and a rise in accidents, particularly in single vehicle accidents, under heat stress conditions induced by extremely hot days and heat waves. Routes may be closed in some areas. **[M]**

Increased demand for climate change mitigation is likely to see an increase in electric vehicles and associated charging points as well as demand for low carbon transport such as cycling. Warmer weather may encourage more people to walk or cycle, delivering health benefits in addition to greenhouse gas reductions. Roadside areas are potentially sensitive to increased electric vehicle infrastructure which may impact the sense of tranquillity and escape. **[L]**

Invasive or other species interactions

Increased atmospheric concentrations of carbon dioxide and nitrogen may see some plants grow more vigorously. Most roads, tracks, and railways already experience some level of vegetation growth, but may require an increase in maintenance. This may also be the case if growing seasons lengthen due to higher annual average temperatures. Some routes may become overgrown and difficult to use, and embankments may become unstable if species composition changes significantly. There may be an impact on the PDNP economy and sustainability of businesses. [**L**]

Other indirect climate change impacts

Fire risk during hotter, drier summers may increase if visitor numbers also rise especially at heather or grass moorland sites near to main routes. This could lead to damage to sensitive areas, wildlife and heritage assets, and increased costs and public safety risk. Routes may need to be closed pre-emptively. Road closures have already taken place due to large moorland fires (for example the 2018 Stalybridge fire) but are likely to have a very limited impact on overall transport into the PDNP. **[L]**

What is the adaptive capacity of transport links into the PDNP]? *[Overall adaptive capacity rating: HIGH]*

There is a very diverse set of transport infrastructure to access the PDNP: five main railway lines, a good range of bus services, several A roads and many minor roads, public access to 500 square km of access land and 2,460 km of public rights of way. The A619/A623 Chesterfield to Barmoor Clough is a key freight route, whilst the A515 is the strategic route for aggregates. Although disruption will occur, the majority of the PDNP should remain accessible and in this way it has a very good adaptive capacity. **[H]**

However, transport networks are by nature interlinked so climate related disruption affecting one can have knock-on effects on others. The overall level of risk facing the sector may be intensified by its interdependencies with other sectors (for example energy where potential interruptions to supply can disrupt rail and road networks and operations). Such potential impacts, in turn, increase risks for businesses. The design and maintenance of transport systems may also need to take gradual climatic changes into account. Some historic infrastructure may already be unable to cope with these changes. Most of the infrastructure should be resilient and able to recover from damage or disruption. Historic scheduled bridges may be more difficult or costly to repair or modify. **[H]**

Responsibility for transport policy at Government level in the UK rests with the Department for Transport (DfT). Network Rail recognises climate change as an important factor in future planning and substantial research is underway to make the rail system more resilient to climate impacts, while Highways England has produced its own adaptation strategy. The DfT has provided local authorities with adaptation guidance on issues such as road surface maintenance. Under the Climate Change Act 2008, 31 transport organisations have produced reports setting out how climate change may impact their business and what actions they have identified to manage the risks. **[H]**

Information and management skills needed to adapt infrastructure is well researched and tested and readily available and is already being assessed and implemented by several of the agencies above. **[H]**

Due to the size and nature of the institutions responsible for maintaining UK transport network and the increasing recognition of the importance of climate change mitigation and adaptation, it is very likely that funding and investment will be available to maintain and adapt major transport infrastructure, including electrification into the 21st Century. **[L]**

Key adaptation recommendations for transport links into the PDNP:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Review and adapt vegetation management to keep routes open.
- Incentivise reduced demand for services through behaviour change and the use of more efficient technologies.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.
- Support changes such as enlarging drainage capacity for roads, railways and other routes to enable them to cope with increases in rainfall, and the implementation of speed limitations during times of extreme temperature.

Improve current condition to increase resilience: Increase structural diversity of the landscape to improve resilience to change

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the landscape in which the feature is found. By doing so the condition of the feature, and therefore its resilience to climate change impacts, should be enhanced.

- Identify alternative and creative ways of delivering services, for example using green spaces to aid flood management.
- Natural Flood Management in the uplands of the PDNP through habitat restoration and woodland establishment is a key adaptation to reduce the impacts of flooding on transport infrastructure.

5.4. Cultural landscapes

Cultural Landscapes

	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Abandoned places of industry	High	Moderate	**High**	118
Boundaries and patterns of enclosure	High	Moderate	**High**	123
Estate lands and designed landscapes	High	Moderate	**High**	131
Lead mining features	High	Moderate	**High**	137
Lowland pastoral landscapes	High	Moderate	**High**	143
Managed moorland	High	Moderate	**High**	148
Prehistoric burial mounds and ceremonial monuments	High	Moderate	**High**	153
Prehistoric and Romano-British settlements, field systems and cairnfields	Moderate	Moderate	**Moderate**	158
Villages associated with medieval strip fields	Moderate	Moderate	**Moderate**	163

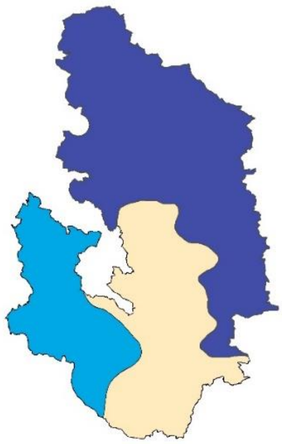
Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

Abandoned places of industry

Overall vulnerability rating

Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:



- Abandoned places of industry

Special qualities:

- Undeveloped places of tranquillity and dark night skies within reach of millions
- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

Across the PDNP there are examples of abandoned places of industry, some dating back hundreds of years. These range from lead workings, mines and lead smelting sites and buildings, to spoil heaps, limekilns, quarries, mills, water management features and a range of smaller-scale industrial processes.

Mining was prevalent in the area and there are remains of various types of mining including chert mines near Bakewell, coal mines at Goyts Moss and Axe Edge, and copper mines at Ecton Hill. Many also have associated soughs which are underground drainage channels built to take water out of the mines. Features associated with lead mining are covered in more detail in 'Lead mining'.

There are also former quarrying sites for minerals, limestone and gritstone, and the production of lime and specialist gritstone products such as millstones.

A number of former railway lines that once also served quarries and mines have since been utilised to become trails for walkers, cyclists and horse riders. See 'Paths, tracks and trails' for more information.

Some of the old industrial buildings and infrastructure remain, like those at Millers Dale on the Monsal Trail where work is being carried out to restore the old goods shed. Formerly the Midland Railway Line, the route takes visitors past lime kilns and abandoned quarries.

How vulnerable are abandoned places of industry?

Abandoned places of industry have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, and a moderate adaptive capacity.

The current condition of these features across the PDNP is variable. Designation as a scheduled monument does provide some protection but only includes a small number of these sites. Climate change could have a major impact on abandoned sites of industry with workings underground potentially at risk from storm events or changes in groundwater levels. While appropriate management can partially counteract climate change, only a limited amount of funding is available.

Overall potential impact rating: HIGH **Overall adaptive capacity rating: MODERATE**

Current condition:

There are a wide range of abandoned industry sites in the PDNP in a variable condition. Some sites are affected by damage from plant growth and/or animal burrowing.

A small number of sites are designated as scheduled monuments providing some protection and detailed information about their condition. There are currently eight sites in the PDNP on the Heritage at Risk register and two of them are categorised as 'industrial'. The Copper mines on Ecton Hill (Staffordshire) are described as being in "generally satisfactory (improving) condition", with a principle vulnerability being from scrub and tree growth. The second industrial site on the register is Alport smelt mill, Harthill in the Derbyshire Dales. This has extensive significant problems including shrub and tree growth and is in a declining condition.

However, it is likely that there are many more sites both scheduled and unscheduled that are at risk particularly from erosion caused by water and wind.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Abandoned places of industry are susceptible to climate change in several ways. Storm events and extremely wet conditions would increase the risk of collapse of underground mining features or the submerging of remains preventing their survey and management. Soils and the features themselves are sensitive to erosion from increased hydraulic action, while structures and archaeological earthworks could be damaged or weakened directly by hydraulic action or the increase in flow of sediment or debris. Such conditions could also affect the ability to undertake some types of survey work as well as being challenging for excavation, particularly on slow draining geologies. Any change to the water table could reduce the water in submerged workings which could also have an impact. [**H**]

Surface structures are sensitive to fluctuations of temperature so any increase in thermal expansion and contraction of stone and soil could lead to accelerated attritional damage. [**M**] They are also susceptible to shrink-swell action especially on clay rich ground. The British Geological Survey has described this process as 'the most damaging geohazard in Britain today'. As a result, monuments could be altered or damaged. Cycles of wetting and drying can be particularly damaging to buried archaeological remains. [**L**]

Human behaviour change

Future desire for renewable energy could potentially see minewater used as an energy source. This would cause a huge amount of potential change to aesthetics and infrastructure of abandoned industrial sites. Ground source heat pumps are likely to be a growth area and it may be that the heat capacity available in minewater could provide heating or cooling in buildings. Research in the USA has shown that acidic minewaters can be used in fuel cells to generate electricity. Such uses of abandoned mines could damage or lead to the modification of a feature unless carried out with sensitivity. [**M**]

Hotter, drier summers could see a rise in tourist numbers, potentially increasing erosion from foot traffic and possibly an increase in vandalism. There may also be an increase in damage to or loss of heritage assets from changing landscape use such as more intensive farming; the use of deep-rooted energy crops; and new developments. There is a small possibility these changes may uncover new sites. [**M**]

Changes in temperature, rainfall and extreme events could have an impact on archaeological earthworks and subsurface remains on farmland. Such features will be sensitive to changes in farming economics and therefore crop types and grazing regimes. A loss of vegetation groundcover on or around structures could lead to an acceleration of damage [**L**]. An increase in storms or drought frequency could lead to changes in land use. Grazing levels may be altered as a result of changes in ground moisture with a possible reduction in cover if drier, or an increase in vegetation if wetter and grazing animals must be removed - both potentially leading to damage. [**L**]

Any efforts to reduce the importation and transportation of minerals from elsewhere may see economic pressure to reopen disused workings. However, there are tight controls in place within the PDNP over such activity. [**L**]

Invasive or other species interactions

Increased annual average temperatures may result in higher populations of burrowing mammals such as badgers, moles and rabbits as well as increased vegetation growth. Stonework and structure foundations and earthworks such as spoil heaps are sensitive to burrowing mammals, and can be damaged or covered by excessive vegetation growth. Stonework may be destabilised, and buried archaeological deposits disturbed. Features may become covered in scrub or vegetation. [**H**]

Changes in atmospheric conditions including increased carbon dioxide levels, coupled with wetter warmer winters may potentially see an increase in the growth in some plant species including trees and shrubs. Physical damage to structures may be accelerated. [**M**]

Nutrient changes or environmental contamination

Increased atmospheric carbon dioxide could increase water acidity and impact abandoned places of industry that relate to lime production, such as kilns and spoil heaps which are naturally alkaline. Land adjacent to other abandoned mineral workings could become contaminated. While this may not impact the feature itself in the short-term, contamination could have a significant impact on habitat and soil in the surrounding area - leading to land abandonment and increased levels of vegetation cover. Changes in plant species on earthworks could damage archaeological remains and lead to increased erosion risk. [**H**]

Climate change may increase the problem of pollution from abandoned mines. Greater storm frequency and rainfall intensity may speed erosion of spoil heap material and sediments, and result in increased contamination of agricultural land downstream. In addition, longer dry spells would allow soluble mineral salts to form which can then be dissolved and discharged during rain events. Land adjacent to abandoned mineral workings could become more contaminated. This could also impact habitat and soil surrounding the feature, leading to changes such as land abandonment and increased vegetation cover. [**L**]

Sedimentation or erosion

Hotter summers and warmer winters could see changes to soil decomposition rates. The stability of structures could be impaired by changes to soil, and the cracking of ground will make them susceptible to damage. Wetter winters could also see structures destabilised by increased soil erosion, reducing the long-term robustness of structures. Archaeological deposits and earthworks may also be compromised. [**L**]

Groundcover on or around structures and earthworks may be sensitive to drought and a loss of vegetation could lead to the acceleration of damage. [**L**]

Other indirect climate change impacts

Hotter, drier summers may lead to an increase in grassland and moorland fires. Groundcover on earthworks and around structures is sensitive to weathering and erosion after fire damage. If vegetation is removed, this in turn may potentially increase the risk of future erosion. [**L**]

What is the adaptive capacity of abandoned places of industry?

[Overall adaptive capacity rating: MODERATE]

Some structures are scheduled and therefore have a degree of protection from damage and changes to farming practices such as ploughing - however, this does not apply to many sites. The most vulnerable designated heritage assets may be included on Historic England's 'Heritage at Risk' register, which means they may be monitored more closely. Management actions at scheduled sites may be able to partially offset climate stressors, however there needs to be mechanisms and funding to achieve this beyond very limited grant funding. [**H**]

Historic England Management Agreements, Environmental Stewardship, National Lottery Heritage Funding and other grant funding is available for conservation and restoration but is very limited. For non-designated heritage assets, funding for conservation and repair is extremely limited. [**M**]

Abandoned industrial remains are a finite resource and susceptible to damage and loss. Appropriate management and conservation actions should be able to at least partially offset climate change stressors if funding is available but in general, large-scale surface and underground workings can be extremely difficult to manage and conserve. [**M**]

There is a good degree of diversity in types and condition of sites and they are found in locations with varying geology, habitat and land use. This increases the adaptive capacity of the resource as a whole. [**L**]

A good level of information and skill is available to make appropriate adaptations and to deal with most climate change stressors. Management advice is available from organisations including Historic England and PDNPA. Scheduled status means these monuments have a better chance of appropriate action being taken than non-scheduled or undiscovered sites. However, around 95% of cultural heritage assets are currently non-designated, so very few abandoned places of industry will benefit from any kind of protection. [**L**]

Key adaptation recommendations for abandoned places of industry:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Ensure that the industrial heritage of the PDNP is properly recorded and embedded into all areas of PDNPA's activities (policy development, interpretation, visitor development etc.).
- Ensure that any climate adaptations can be reversed to prevent long term impacts on features.
- Nurture collaborative networks to build capacity for monitoring (e.g. P*eak District Mines Historical Society*, local interest groups).
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

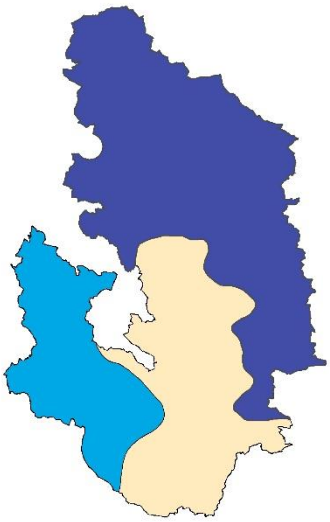
- Increase knowledge about what assets exist, and their condition, to help determine which specific sites in the PDNP are most in need of protection.
- Undertake regular monitoring (including at landscape scale) of selected sites to identify those sites likely to be most vulnerable in terms of archaeology and ecology.
- Monitor outcomes of any change to sites. Select representative samples to monitor on sites where management actions are being implemented and sites where they are not.
- Put forward key sites for scheduling.
- Implement suitable natural flood management techniques in valley bottom sites, such as mills.

Boundaries and patterns of enclosure

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:



- Dry stone walls and hedges including single walling
- Variety of wall types and wall furniture
- Boundary markers and features
- Banks, ditches and other earthworks
- Pattern of Enclosure - Smaller scale mosaic of upland farmed enclosures, lowland pastoral landscapes, open moorland, river valleys & species rich grassland
- Fossilised medieval field systems - strip fields & evidence of Medieval open field farming (South-West Peak) shape of wall, strip field pattern in modern dry stone landscape (White Peak)
- Irregular and semi-regular enclosure including prehistoric field systems
- Field pattern of enclosed in-bye land and open moorland grazing
- Enclosed farmland
- Repeating pattern and rhythm of dry stone walls
- Pattern of large square enclosure on the plateau, C18th and C19th parliamentary enclosure
- Post medieval enclosure

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Landscapes that tell a story of thousands of years of people, farming and industry
- Characteristic settlements with strong communities and traditions

Feature description:

Boundaries and patterns of enclosure, including type and size, are distinctive in the different areas of the PDNP.

Both dry stones walls and hedgerows have been used to enclose land for hundreds of years. They mark the boundaries of fields across the PDNP and are a prominent feature of the landscape. Large upland areas of the Dark Peak remain open but gritstone dry stone walls are used as one way to define ownership boundaries. Dry stone walling and hedges figures for 1991 revealed 8,756 km of dry stone walls and banks and 1,710 km of hedgerows in the PDNP. Although difficult to date, some dry stone walls are believed to go back to medieval times and Romano-British foundations underlying later stone walls have been recorded. Other features used as ownership boundaries such as roads, tracks, and natural features are addressed elsewhere. See ‘Paths, tracks and trails’.

In the White Peak dry stone walls made from limestone are prevalent. Smaller, narrow fields found around villages are evidence of the earlier enclosure of strip farming. Former common land was often the focus of Parliamentary Enclosure Acts in the late 18th to early 19th century and tends to feature more regular medium to large sized fields, with much straighter boundaries. The walls themselves are built without mortar and vary in construction. The type of stone used depends on the geology of the area in which they were built with limestone, gritstone and other sandstones being used. Boundaries built using quarried stone are generally neater than those made from random stone, but both are essential components of the landscape.

Boundary markers can also include natural features such as rock outcrops or ridge lines. Other features that remain include guide stoops. Dating back hundreds of years these stone waymarkers helped travellers navigate remote routes and were placed where paths intersect, often showing the direction of the nearest market town.

Hedgerows are also an important historical feature, particularly in the White Peak and South West Peak. They tend to be in the low-lying land in areas such as the Derwent Valley or on the fringe of the Derbyshire PDNP and are predominantly blackthorn and hawthorn. In areas of the Dark Peak holly has also been used as a hedging plant.

The patterns of field enclosure provide valuable information on landscape change and historic land use, and reflect time-depth in the landscape. Medieval field strips fossilised by later walls are a characteristic feature of the White Peak landscape, but other types of enclosure pattern are equally significant. Earthworks, such as lynchets, ridge and furrow, ditches and banks also define former or current fields.

Highly significant prehistoric field systems are present in a number of areas, including open moorland and agricultural areas. These may be seen as earthworks at a completely different orientation to the current boundaries, although archaeological research shows that prehistoric field patterns can be echoed in the pattern of current boundaries, for example at Roystone Grange.

The varying patterns of enclosure that are found in the PDNP are extremely important to the character and heritage value of the PDNP landscape.

How vulnerable are boundaries and patterns of enclosure?

Boundaries and patterns of enclosure have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an often poor general condition, and a moderate adaptive capacity.

It is difficult to ascertain the overall current condition of dry stone walls as it is varied. However the condition of hedgerows is viewed as poor. Extreme weather is one of the key potential impacts increasing deterioration and maintenance costs leading to a greater risk of abandonment. Another is changes to land use, which may mean boundaries are removed to enlarge fields. Changing farming practices such as an increase in ploughing may affect earthwork features. Walls in poor condition are also often used as a source of stone to repair other walls.

There is limited funding available to improve these features and there is currently a shortage in terms of the number of people with the necessary dry stone walling skills needed for management and maintenance. Even the repair and rebuilding of walls, whilst retaining the landscape appearance, can remove or alter historic information that is very valuable (such as the physical relationships between features, or distinctive construction styles). Planting could improve hedgerows condition by filling in gaps and diversifying species. If not designated, prehistoric field systems are vulnerable to landscape change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

In many cases the condition of boundaries and patterns of enclosure vary depending on the area in which they are found.

Hedgerows in the PDNP are considered to be in a generally poor condition often due to a lack of sympathetic management. Many are overgrown or have gaps, and are species-poor when compared to other areas. They are mainly made up of hawthorn and blackthorn although in some areas include holly and hazel.

Dry stone walls are in a variable condition, with many in a poor condition due to lack of maintenance, the removal of stones, or even vandalism. It is difficult to date dry-stone walls but some are believed to date back to medieval times while others are said to have Roman and prehistoric foundations. During the 1970s and 1980s, over 250 km of field boundary was lost. This occurred for a number of reasons including a need to increase entrances and gateways for larger machinery, and a trend to increase the size of fields for agricultural efficiency. Over 20 years ago it was estimated by the Countryside Commission that in the UK as a whole as many as 50% of walls were derelict. Such figures for the PDNP are not available at the time of writing.

Limited funding to rebuild damaged walls or replant hedgerows has been available from a number of countryside agencies. During the 1980s, 11 km a year were rebuilt and between 1990 and 1996 that figure rose to 30 km a year. Stone wall restoration has also been included in environmental stewardship agreements. By 2011, 442 km of restoration in the Dark Peak had been included in such agreements. Whilst there has been a rise in interest in dry stone walling, there remains a limited number of people with the necessary skills to repair, restore or rebuild these boundaries.

Although the rate of boundary repair in the PDNP is known to be increasing, many of the components that make up these landscape-scale patterns of enclosure are either in poor condition, or under threat. This threat is often from factors unrelated to climate change, such as continued agricultural improvement and the reworking of mineral resources.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Both dry stone walls and hedgerows are sensitive to greater extremes of temperature as a result of climate change, and increased annual average temperatures. Hotter summers and warmer winters could lead to longer plant growth seasons. Dry stone walls could be structurally threatened by increased thermal expansion and contraction of the stone and soil and an increase in wall flora such as ivy. This may accelerate the speed of deterioration while increasing maintenance costs and the threat of abandonment. Conversely, this could create a new habitat for wildlife. Hedgerows are sensitive to changes in plant growth and shading which in turn could change the composition of understory flora and associated wildlife. **[H]**

An increase in storms and extreme weather could see dry stone walls and wall furniture likely to suffer from increased weathering, while the stability of walls and boundary markers could be compromised in some areas. In hedgerows, there could be a loss of trees and other woody species due to severe drought, or the loss of mature and older standard trees due to storms creating large gaps. Prehistoric field system earthworks may also be damaged by storm events and weathering which can also have an impact on vegetation. [**H**]

Drier summers and wetter winters could affect ground conditions and the stability of boundaries through an increase in the process of shrink-swell, particularly on clay soils. **[M]**

Limestone is sensitive to chemistry changes and pollution, so an increase in atmospheric carbon dioxide could lead to further erosion of limestone features in dry-stone walls such as gateposts. A loss of lichen species – which can be used to date structures - could occur due to atmospheric pollution. [**M**]

Hedgerow plants and trees are sensitive to changes in rainfall, which could also risk erosion being accelerated. Drought could reduce ground cover, increasing erosion further. Decreases in summer rainfall could lead to increased mortality and die-back of certain hedgerow tree species such as beech. Drought may also increase trees' susceptibility to pests and diseases. In addition, prolonged flooding in the growing season due to extreme weather events could see woody species at risk of dying. Wet ground conditions would make winter trimming of hedgerows more difficult and therefore it may be carried out earlier in the year – decreasing their value to wildlife as a food resource. Increased wet soil conditions could cause damage to soil structure, also leading to increased die-back of hedgerow trees. [**M**]

Human behaviour change

Both hedgerows and dry stone walls are sensitive to agricultural changes on the land they bound. Wetter winters and drier summers could lead to changes in land management practices. An intensification of farming may lead to a rise in offsite impacts such as pesticide drift and nutrient enrichment. Intensification could also lead to a reduction in the use of buffer strips and margins that protect hedges. Wetter winters could also increase the need for modern barns for housing livestock, potentially altering the character of the landscape, particularly around villages associated with fossilised strip fields. [**H**]

If land were to be converted to arable use, it would be likely to cause the loss of traditional landscape features including stone walls and hedges - as fields are enlarged and ploughed. There would be complete loss in some areas and the reduction of extent in others. If boundaries are removed or ploughing increased this could damage their relationship to buried archaeological remains and adversely affect prehistoric field system earthworks. There are however many other variables in addition to climate change that will influence future land use, and so confidence is low. **[L]**

Hedges are sensitive to storms and extreme conditions so it may mean they have to be managed differently, for example by planting different species, reducing their height, or removing standard trees to minimise storm damage. This could decrease their value as a resource for wildlife and as cultural heritage features. An increase in extreme events such as flooding is likely to increase economic pressure on pastoral farmers, potentially leading to some areas becoming uneconomic to farm. This could have a high impact on the maintenance of boundaries. **[L]**

The character of agricultural landscapes could be sensitive to increased demand for renewable energy sources if energy infrastructure such as wind turbines or solar panels are installed. An increased desire for trees as carbon dioxide sinks could lead to the planting of trees in hedgerow gaps or the creation of new hedgerows along field boundaries. This would improve wildlife connectivity, increase biodiversity and create habitat for nesting birds, mammals and invertebrates. However, if hedges replace walls this would lead to loss of historic landscape character. The traditional look of patterns of enclosure in the landscape could also be lost or degraded through changing farm practices - both diversification and intensification. **[L]**

Invasive or other species interactions

Atmospheric changes coupled with increased annual average temperatures could lead to more rapid plant growth, which could accelerate damage to dry-stone walls and earthworks, for example trees growing close to the structure. Hedges may also need increased maintenance. If grazing regimes change or land is abandoned, increases in scrub growth may see the traditional look of the various patterns of enclosure degraded or even lost. Conversely, an intensification of agriculture associated with the potential for increased crop growth could also have a negative impact on these patterns. [**M**]

Increased annual average temperatures could see a rise in plant pathogens and higher populations of burrowing mammals such as badgers, moles and rabbits. Hedgerow plants and trees sensitive to disease could be damaged or die off, changing hedge composition and condition and possibly leading to the loss of key species. In areas with a high concentration of burrowing mammals increased damage could be caused to walls and earthworks, leading to an increased need for repair where they are destabilised. [**M**]

Warmer, wetter winters could see an increase in the occurrence of livestock feed crop pests, liver fluke and other livestock diseases - particularly those transferred by insects such as the bluetongue virus. **[M]** Factors such as these affecting the financial viability of the pastoral system could have profound impacts on the future of farming in the PDNP, and consequently reduce the need to maintain field boundaries.

Other indirect climate change impacts

Warmer and drier conditions would affect hedgerow species such as beech, hawthorn and rowan that need a period of colder weather to ensure flower and fruit production. Any reduction could affect food sources for wildlife. Drier conditions may also mean hedgerows are damaged or lost to wildfire. [**H**]

Drought conditions may mean the very small number of managed meadows remaining in the PDNP would be more susceptible to grassfires. The resulting bare ground could more easily be eroded. However, this risk is considered minimal, and unlikely to have a meaningful impact on the long-term structure or extent of patterns of enclosure. **[L]**

Nutrient changes or environmental contamination

Wetter winters may increase the perceived need for fertilizer application if leaching increases. In addition, pressure from 'pest' species due to warmer winters may lead to an increase in pesticide application. Both factors could affect hedgerow plants – decreasing the diversity and condition of the species they contain. Drift from pesticide application would also lead to the loss of lichens and bryophytes on stone walls. This would negatively affect invertebrates and other wildlife living in hedgerows and stone walls, and change the character of the components which make up the patterns of enclosure. **[L]**

Sedimentation or erosion

Dry stone walls and boundary markers are sensitive to stability of soils under the base. They may be damaged if wetter winters saturate the ground, and extreme storm events become more frequent resulting in high levels of surface run-off. Hedges are also sensitive to this change. This could lead to the acceleration of damage and a decrease in structural stability due to run off. Structures on clay soils are likely to be most vulnerable. Increased maintenance costs could see some areas of dry stone walling replaced with fencing which may alter the landscape character. **[H]**

What is the adaptive capacity of boundaries and patterns of enclosure? ***[Overall adaptive capacity rating: MODERATE]***

There are very diverse patterns of enclosure across the PDNP when taken as a whole, meaning that there is a high chance of some types surviving in their current form despite future impacts. Hedgerows are composed of different woody species. Hedges with low diversity, for example holly only, have lower adaptive capacity than mixed-species hedges and are therefore more vulnerable. Many PDNP hedgerows are in poor condition with lots of gaps and low diversity with only one or two species. [**H**] However, they have a good chance of recovery from change, especially with planting to fill in any large gaps. Areas where dry stone walls and hedges are less continuous and have not been well maintained are likely to be less resilient to change. [**M**] Dry-stone walls vary in building material and method of construction. Single walling is likely to be less resistant to damage than thicker double walls. Dry stone walls require continuous maintenance in order to recover from change, completely depending on the level of human management. **[M]** Limestone walls may be at a higher risk of erosion and weathering than gritstone walls, but this will vary by location. [**L**] In terms of fossilised strip field boundaries, those found on the fringes of the area that are demarked by hedges may be less resilient than those marked by walls which tend to be found on the plateau itself. **[L]**

Environmental land management schemes are available for the restoration and management of both hedgerows and stone walls. There are other funds available to restore walls through PDNPA and Natural England but these are variable and now much reduced. Some funding options are likely to be available in the future for maintaining landscape - however options are likely to remain limited and current trend is that land in the PDNP with an agreement is declining. It is not known what future priorities will be. Any funding available will be vital for offsetting the effects of climate change. **[H]**

In the majority of cases, planning permission is needed to make changes to agricultural land or commercial property. The system of control over land use change within the park should offer at least a partially effective mechanism for conserving the landscape. However, changes will still occur if keeping livestock on pasture becomes economically unviable or there is pressure to intensify land use. **[M]**

Important hedgerows are protected by the Hedgerows Regulations 1997. Stone walls are not legally protected however government guidance states that only in special cases can a stone wall be removed or stone take from it. Some protection is also provided through the Environmental Impact Assessment regulations. Future environmental land management schemes or cross compliance may include protection of dry stone walls, especially if they are of a certain length of historic or landscape importance, however this is currently unclear. Stricter policies or regulations could help enforce maintenance of existing walls. **[H]**

Hedgerows have a good chance of recovery from change, especially where planting occurs to fill in any large gaps. Although species composition of some hedges may change due to of climate change, their overall function should remain. Dry-stone walls need management and maintenance to survive and recover from change. They therefore have good potential for resilience provided human intervention occurs. [**M**]

A good level of information and skill is available to make appropriate adaptations and to deal with most climate changes, especially for hedgerows. Dry stone walling is slowly becoming popular again, however there is still a skills shortage. There is extensive knowledge about different construction methods and how to best repair or reconstruct a wall. Advice is available from The Dry Stone Walling Association. Prehistoric field systems have a much lower adaptive capacity as they generally survive as earthworks. Because of diversity in land ownership, a great diversity in management, information and skills available to adapt and conserve the landscape it is likely that some features will survive whilst some will decline. The PDNPA's Historic Landscape Character Assessment is vital to understand how existing patterns relate to past land use and may provide important understanding of how we manage land in the future. **[M]**

Key adaptation recommendations for boundaries and patterns of enclosure:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Monitor boundary changes at a landscape scale, for example quantify the loss of walls and hedges. Ensure that management mitigates piecemeal changes to enclosure patterns that may seem insignificant on their own, but that can have cumulative and large impact upon landscape character over time.
- Encourage the use of agricultural buffer strips to protect hedges from human behaviour changes (e.g. intensification of agriculture) which may occur because of climate change.
- Ensure management practices allow for the maintenance of walls and historic field patterns. Explore opportunities in future environmental land management schemes.
- Undertake research to understand the significance of different boundary types and patterns. Appreciate that boundaries may have different components, including natural features. Also appreciate the time-depth in enclosure. For example, prehistoric boundary patterns may underlie the dominant, later enclosure patterns, and be visible only as earthworks. This will help inform future adaptation planning.
- Help land managers within the PDNP to enter into environmental stewardship type agreements or secure funding for capital works by providing assistance with advice and logistics - see Moors for the Future Partnership's Private Land Project as a possible model.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Focus efforts on identifying priority areas and restoring and reconnecting fragmented hedges and walls in those areas. It is important to avoid further loss and restore boundaries. This will improve their function as wildlife corridors and improve their overall resilience to change. Ensure targeted conservation efforts are informed by historic character and relative significance.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Diversify the landscape and increase the proportion of tree cover to reduce the impact of flooding from rivers and overland flow on boundaries.
- Restore and connect fragmented hedges with native species sourced from further south in the UK. Increase species diversity of hedges to buffer against single species losses.

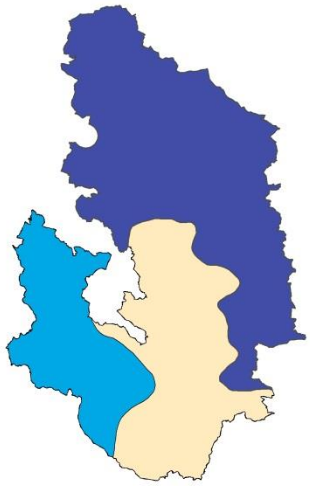
Estate lands and designed landscapes

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:

- Estate lands and designed landscapes



Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Undeveloped places of tranquillity and dark night skies within reach of millions
- Landscapes that tell a story of thousands of years of people, farming and industry
- Characteristic settlements with strong communities and traditions

Feature description:

Across the PDNP there are a number of country houses, estate lands and designed landscapes, including Chatsworth, Haddon, Thornbridge and Lyme Park. For the vulnerability assessment of the houses within these landscapes, please see 'Country houses'.

These estates date back hundreds of years, growing up around a prominent property and sometimes incorporating villages and farms. The collection of buildings has a distinctive style and is usually built with similar materials. The associated parkland can be extensive and aspects are often designed.

At Chatsworth for example, the successive Dukes of Devonshire engaged the services of landscape architects and designers, including Henry Wise, Capability Brown and Sir Joseph Paxton, who input to the design of the landscape. This work includes the creation of water features, bridges and follies. It remains one of the least disturbed parkland landscapes in terms of archaeological earthworks and below-ground archaeology as large parts have not been ploughed for over 250 years.

At the privately owned Thornbridge the gardens within the estate incorporate three temples, numerous statues, 46 urns and two grottos. Many of the statues were brought to the estate in the 1930s from the demolition of Clumber Park in Nottinghamshire while others are believed to have been gifts from Greek government.

These estates are enjoyed by visitors as tranquil places that have a sense of history, continuity and tradition. They are also appreciated for the views of the landscape they create, and for the evidence they contain of settlements, farming and land management through time.

How vulnerable are estate lands and designed landscapes?

Estate lands and designed landscapes in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and moderate adaptive capacity.

Many estate lands are well managed and have ongoing maintenance and development plans. The current condition for those held in private ownership is more difficult to determine. Extreme events including heavy rainfall and flooding, but particularly drought, could have a significant impact on estate lands and designed landscapes. There is capacity for adaptation as most have a management plan or similar system in place. Some estates are also given protection through their registered status.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

It is difficult to ascertain the condition of estate land and designed landscapes.

Generally estate lands and designed landscapes appear to be well managed. The National Trust is the custodian of a number of sites including Lyme Park, and Chatsworth is overseen by the Chatsworth House Trust. They have considerable resources to call upon and include details of their management plans on their websites.

For example, at Chatsworth one extensive project will include planting more than 250,000 flowering perennials, shrubs and trees in a previously undeveloped 15-acre area of garden. The Trout Stream is another area which has been redeveloped.

At the National Trust's Longshaw Estate a new native tree nursery is being set up. It is made up of a diverse number of species and aims to replace trees that have been lost and to create new woodland.

Many estates that are held in private ownership do not publicise their plans and resources, so their condition remains unclear.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Storm events and flooding may impact features such as buildings, farmland, woodlands, gardens and parkland structures including follies and towers. Flooding and standing water could exacerbate erosion of soft sandstone and new flood defences may change landscape aesthetics. Buildings are also sensitive to damage from poor or inadequate rainwater goods. **[H]**

Plants in designed landscapes may suffer during intense continuous periods of rainfall. Old parkland trees could be vulnerable in storm events, potentially leading to the loss of associated habitats for wildlife, although there could be more opportunities created for dead wood invertebrates. Any damage could also impact the aesthetics of the estate. If properties and estates are deemed unsafe they may have to close temporarily or even permanently. **[H]**

Water shortages caused by droughts may see fountains and ponds not in use which may impact tourist numbers and wildlife. Some of the trees and plants that make up designed and historic landscapes are sensitive to drought which could lead to their loss. **[H]**

The drying out of certain geologies, clay for example, can increase subsidence affecting historic structures which are also sensitive to geological shrink and swell. Changes in rainfall may see the timing of planting and species used in gardens altered. These conditions could also affect the stability of buildings and other structures. **[H]**

Limestone structures are sensitive to water chemistry changes and pollution which could increase erosion of buildings, statues and dry-stone walls, and impact lichens and mosses. **[L]**

Human behaviour change

Drought conditions could lead to increased competition for water and impact irrigation for parks and gardens. As a result parkland landscapes may alter as drought resistant plants thrive. Lawns and gardens could become dry which can affect the aesthetics of the landscape. Water features may also be impacted if choices have to be made about where water is directed. Drought could lead to the drying up of springs which could cause disruption to domestic and agricultural water supplies. **[H]**

Increased temperatures may see parklands susceptible to changes in tourist numbers. Gardens and parklands could be damaged by a rise in foot traffic and fields and their historic and natural environmental components could be damaged if used as car parks and large events spaces. **[H]** Conversely, if the aesthetics of these estate landscapes are negatively affected by climate changes, this may lead to a reduction in visitor numbers and therefore a reduction in viability of estates that are dependent on visitor fees. **[L]**

Parkland is sensitive to changes in stocking levels. Flooded land would not be suitable for grazing so scrub may develop and shortages of water for stock during summer could also make some pastures unsuitable. Nutrient inputs through farming practices could also be increased if the agricultural productivity of land needs to be raised through intensification. Farm buildings could become redundant or be altered due to these changing farm practices, resulting in a change to the landscape aesthetics. **[H]**

Flooding may also impact buried archaeology. Flood adaptation could be added to buildings and structures and flood defences added to the parklands. Tree establishment may rise to help reduce overland runoff. Such disturbance could put buried archaeological remains at risk. **[L]**

Other measures to adapt to climate change such as installing air conditioning or rainwater harvesting may have a negative impact on this historic asset. Mitigation measures such as solar panel installation or upgrading the thermal efficiency of buildings by increasing insulation could have a similar impact. The characteristics of historic and significant buildings may be sensitive to modernisations and building aesthetics may be changed. **[L]** Increased demand for renewable energy could see the introduction of wind turbines and lead to a reduction of historic landscape character, amenity value and tranquillity. **[M]**

Invasive and other species interactions

Increased temperatures may see an increase in plant diseases such as *Phytophthora* and ash die-back. Different flora and fauna could also spread into parklands as the climate shifts. Plants in designed landscapes, trees in particular, are susceptible to this competition and pathogens such as ash die-back. The biodiversity and aesthetics of the landscape could be altered. **[H]**

New pests and diseases such as insect and fungal infestations could damage historic buildings and organic artefacts at a time where traditional repair materials may become increasingly difficult to source. Animal diseases may become more prevalent changing farm stock choices and could ultimately alter grazing patterns. **[H]**

Any land left under water for some time following flooding could be vulnerable to an increase in pests and diseases. It could also alter garden and parkland landscapes leading to the loss and damage of some plant species. **[M]**

Changes in atmospheric conditions including increased carbon dioxide levels may potentially see an increase in the growth rate of some plant species. These may include invasives like Japanese knotweed, Himalayan balsam, trees or shrubs. This could cause structural damage to buildings and statues. Increased plant growth rates may also mean that additional garden maintenance is required. **[L]**

Other indirect climate change impacts

Hotter drier summers could see estates disrupted or damaged by fire. There may be a risk of injury to people and livestock, and buildings may need to close while repairs take place. This could put a greater demand on financial resources. Any damage to woodland and mature trees could also mean a loss of wildlife habitat, making these estates less enjoyable to visit. **[M]**

Sedimentation or erosion

Increased rainfall could see a rise in flooding and erosion. As many estates are situated close to rivers this could damage parkland and any buried archaeology in the floodplains. Structures such as bridges may suffer direct damage from flooding, while high water tables can impact the foundations and stability of structures, such as historically significant garden walls. **[H]**

Nutrient changes or environmental contamination

Wetter winters may increase the need for fertilizer application if leaching increases. In addition, pressure from pest species due to warmer winters may lead to an increase in pesticide application. This could change pasture productivity and plant species composition in gardens which may negatively impact invertebrates and other wildlife living on estates. **[L]**

What is the adaptive capacity of estate lands and designed landscapes?

[Overall adaptive capacity rating: MODERATE]

Designation by listing provides some protection for buildings from inappropriate work as well as a system of monitoring condition so problems are noted and action can be taken. Non-designated assets, such as farmsteads, are subject to other policies, such as PDNPA planning policies, helping to prevent unsympathetic alteration. Historic England's Heritage at Risk Register is a reasonably robust way of tracking some of the most vulnerable buildings, but is missing many features which could also be considered to be at risk. **[H]**

While estate lands and designed gardens have no specific legal protection there are four within the PDNP that are Registered Parks and Gardens which provides limited protection. They sometimes have detailed management plans. Estate lands are listed as a landscape character type by the PDNPA and have an associated strategy and guidelines. This identifies priorities for landscape protection, management and planning. **[H]**

Country houses can recover from weather events but restoration may be at a large financial cost. Restoration of original features will not always be possible and so this historic information can be lost. Preventative measures may alter property aesthetics but reduce the risk of major damage or loss. The National Trust has done work already elsewhere in the UK to increase the water capacity of downpipes so they can better handle large volumes of water in storm events. **[H]**

Depending on their specific design parklands may have a better adaptive capacity to recover if they have a variety of plant species. Garden design may be optimised for new climate restrictions. Trees are a defining aspect of parkland but there is less scope for selecting trees to plant that can cope with future climate stressors, therefore putting that aspect at greater risk. Historic structures and buried archaeology could not recover from being washed away in a flood event or fire. **[H]**

A good level of information and skill is available to make appropriate adaptations and to deal with the aftermath of extreme events and fire. Advice is available from Historic England, PDNPA, National Trust, and Natural England. Farmed estate lands and parklands have been managed for a long time and land owners have the knowledge to cope with changing requirements. **[M]**

Fragmentation of field boundaries and woodlands would have a detrimental impact on landscape character. Maintenance and improvement of existing features will help overcome or help offset climate change stressors. **[M]**

The PDNP contains a number of estate lands and designed landscapes with various building types, plant species in gardens and woodlands, and farming strategies. A mixture of building materials and plant species gives them greater adaptive capacity than more uniform landscapes but conversely this depends on what aspect is being considered. Many attributes of these landscapes and estates are unique and several of these estates are close together putting them at higher risk in extreme events. **[M]**

Estates such as Chatsworth and Lyme Park have access to a large pool of resources and expertise to draw upon. However for some estates like Haddon and Thornbridge it is not known what resources they have and they may be more limited. **[M]**

Key adaptation recommendations for estate lands and designed landscapes:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Carry out research and survey into designed landscapes, especially those at a smaller scale that might not previously have been recognised as significant. This will help inform future adaptation planning.
- Increase the resilience of the surrounding landscape to help create a buffer for estate lands and designed landscapes. Form estate level plans for improved climate resilience, such as improving moorland condition to reduce flood risk.
- Nurture partnerships with big estates and landowners.
- When planning any future adaptations ensure existing archaeological complexity is taken into consideration.
- Consider the cumulative impact on estate lands by visitor pressure and events.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Identify field boundaries that are at risk and work to restore or improve them.
- Manage and replace veteran trees (scattered trees in historic parklands and in field boundaries are a key characteristic of the Derwent Valley).
- Harvest and store rain water at drought sensitive sites (already in place at some properties).

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Increase woodland establishment and enhancement of habitats where appropriate, while maintaining the significance of key views and designed elements. This will strengthen existing landscape character, whilst in the future lower lying landscapes adjacent to the river could provide useful floodwater storage services.
- Increase the diversity of planting in parklands to make them more resilient.

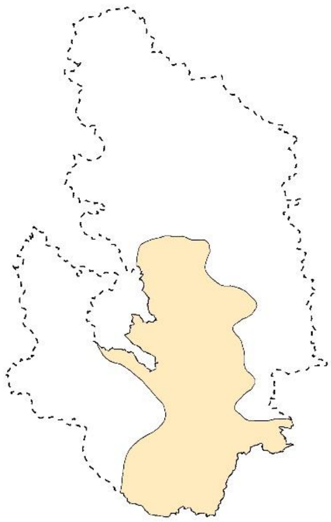
Lead mining features

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:

- Lead rakes and mines - large and small scale extraction & processing infrastructure
- Below ground workings



Special qualities:

- Internationally important and locally distinctive wildlife and habitats
- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

Lead mines were once a familiar sight across the White Peak.

While some of the features of mining can be seen at the surface, many are largely underground; the underground workings can be deep and complex. Many mines have associated soughs - underground drainage channels - built to take water out of the mines. See 'Reservoirs and water management' for further discussion of such water management features.

Some of the most prominent surface features still visible are lead rakes. These are composed of the working areas and spoil that was left when miners had extracted the lead ore. These hillocks are viewed as an incredibly important for the calaminarian grassland habitat they support. Approximately 30 ha of calaminarian grassland and lead sites have been mapped in the PDNP, the vast majority of this being priority habitat.

Relatively few lead mining sites have designated status. A total of 163 sites within the PDNP are included in the PDNPA Inventory of Regionally and Nationally Important Lead Mining Sites, while nine are also seen as important lead mining landscapes. There are many more lead mining sites of local significance.

Intact buildings relating to lead workings are rare. One fine example, the Magpie Mine at Sheldon, dates back to 1740. It was also the final working lead mine in Derbyshire and closed for the final time in 1954. This site is one of the most complete groups of historic lead mining buildings, with an engine house, chimneys, and other structures.

How vulnerable are lead mining features?

Lead mining features in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a highly variable current condition, and moderate adaptive capacity.

Lead mining remains in the PDNP are in variable condition, some high value sites are in very good condition, but many other hillocks and sites of ecological interest have been degraded. Changes in the climate could have a major direct impact on these sites altering the composition of the important calaminarian grassland habitats, while increased storm events could lead to pollution further downstream and damage to remaining archaeological features. Spoil tips and workings often comprise loose soils and deposits that are very vulnerable to erosion by wind water and abrasion. Surface features are particularly vulnerable to agricultural improvement, such as infilling and levelling. While some calaminarian grassland species have capacity to adapt, sites are fragmented and recovery from damaging events may be slow. Archaeological features have less adaptive capacity and should be considered a non-replaceable resource. Factors which may help to partially offset climate stressors include the good diversity of archaeological features which still exist, the diverse micro-topography of the remaining lead landscape, and the relatively well-studied nature of assets in the PDNP.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

There are significant archaeological remains of lead mining in varying condition. The total of 163 regionally important sites and nine important lead mining landscapes within the PDNP cover a wide range of types of mining remains and ecological habitats. There are many more sites that are not designated or on the list of regionally important sites, but that contribute to the historic mining landscape.

A small number of building features are in very good condition such as those at Magpie Mine and Bateman's House, and most feature types have some examples in a good condition.

Most include hillocks or relatively common surface features such as shafts, access levels and dressing floors. Around two thirds include rare or special surface features including engine houses and other mine buildings and drains, and most have underground features**.**

Many surface remains have been lost over time, some as a result of the materials originally discarded by miners being reworked to access fluorspar and barite – both of which are now more valuable than the lead. Others have been lost due to changes in land use, for example being levelled or infilled for agricultural purposes.

Lead mine sites are heavily polluted. They are home to calaminarian grasslands, as the metallophyte species are adapted to this pollution. This unique habitat is irreplaceable, and some contaminated soils will be washed away each year. The PDNP is currently a UK stronghold for these grasslands.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Drier summers could impact the metallophyte Pyrenean scurvy-grass as it favours wet, open habitats. Dry periods may reduce its survival and it may even be pushed out of some habitat. It may only be found in one area within the PDNP at present so this could result in it being lost from the PDNP calaminarian grasslands entirely. **[VH]**

Increased frequency and severity of storms would increase water flow through mines and soughs and cause structural damage underground. Heavy rainfall could damage surface features, for example by washing away loose hillock material. Flooding of mines would reduce access for cavers and mine explorers to carry out archaeological surveys and conservation assessments. **[M]**

An increase in annual average temperatures could see the nationally scarce metallophyte, Alpine penny-cress, potentially colonise more of the PDNP as conditions become more favourable. However another metallophyte, the mountain pansy, is already at its southern range limit in England and could be lost from the PDNP. **[M]**

As building materials are susceptible to extreme temperatures through the processes of thermal expansion and contraction, higher summer maximum temperatures may increase the rate of structural degradation. **[M]** Atmospheric changes that increase the amount of acid rain could damage some features, especially structures made from soluble limestone. **[L]**

Human behaviour change

Future desire for renewable energy could potentially see minewater used as an energy source. The use of ground source heat pumps is expected to increase and it may be that the heat capacity available in minewater could provide heating or cooling. Research in the USA has shown that acidic minewaters can be used in fuel cells to generate electricity. Soughs could be converted to power generators. Such changes could damage existing structures and the historic character of sites may be lost or impaired. **[H]**

Changes in land use could affect the viability, stability and survival of lead mining remains. If other sites become unsuitable for grazing, farmers may consider improving grassland on sites previously left unimproved. Hillocks and other surface features may be destroyed to allow livestock on the site. However, stock are likely to be excluded from areas where there is a danger to livestock from lead contamination. In addition, calaminarian grassland could reclaim abandoned sites if metal pollution levels are high enough. **[H]**

Increased erosion and water run off on lead rakes could see a decrease in pollution on the site and instead increase pollution downstream. More balanced pollution levels may favour moving livestock onto lead sites, destroying hillocks and other lead mining features and changing the grassland species composition. Efforts may also be made to eliminate sources of pollution before they enter important water courses. This may lead to destruction of lead polluted habitat, severely reducing calaminarian grassland. **[L]**

Both surface and underground features could be susceptible to increased damage if visitor numbers increase. Lead mining surface remains are fragile and can be damaged by 4x4 vehicles using them as obstacle courses, for example. Some underground mining features are extremely delicate and vulnerable and dangerous or impossible to access. **[M]**

Sedimentation or erosion

Increased storms and rainfall intensity could increase pollution originating from abandoned mine features. This could include the erosion of spoil heap material and its movement onto agricultural land downstream. In addition, long periods of dry weather spells allow mineral salts to crystallise, which can then be quickly dissolved during subsequent rainfall. While lead pollution spreading downstream may create new opportunities for metallophytes, there is also a poisoning risk for livestock in areas where it is deposited. **[VH]**

An increase in water acidity due to raised atmospheric carbon dioxide levels could increase the rate of minerals being dissolved, leading to lead or other heavy metals leaching out of the soil. In such areas, non-metallophyte species could become more competitive, reducing the calaminarian grassland specialists present. **[H]**

An increase in hot, dry periods would cause cracking of the ground and would be likely to increase damage to built structures associated with lead mining. A rise in frequency of these events could speed up the degradation of surviving archaeological features particularly on clay soils. **[L]**

Invasive or other species interactions

A rise in annual average temperatures including warmer winters could result in the number of burrowing mammals such as moles, rabbits and badgers increasing. Built surface features could be at risk of being undermined by burrowing. **[L]** Changes to the character of calaminarian grassland could also occur as some species already at the southern end of their range decrease. **[M]**

Atmospheric changes including increased carbon dioxide and nitrogen levels could increase the vigour of some fast growing plant species potentially altering the competitive balance of grassland leading to a decrease in metallophyte species or other rarer grassland species particularly where metal pollution levels have been reduced through other processes. **[L]**

Changes in atmospheric composition including increased carbon dioxide and nitrogen levels may potentially see an increase in the growth in some plant species. An increase in scrub or tree growth could impair the integrity of remaining built structures, for example by roots damaging the foundations of surviving buildings such as engine houses. **[L]**

What is the adaptive capacity of lead mining features? *[Overall adaptive capacity rating: MODERATE]*

A good variety of features associated with lead mining are present, with at least some of each type in good condition. Different types of features and sites have varying levels of significance, depending on factors including types of feature present, their rarity and age. However, the overall number of features is relatively small, so damage or degradation of any would be a significant loss. **[VH]**

In terms of some of the calaminarian grassland species, spring sandwort and mountain pansy are more widespread across sites, but Alpine penny-cress and particularly Pyrenean scurvy-grass are less common and are likely to be less resilient to change. The habitats that occur on lead surface features are diverse, often within small areas, due to diverse topography of the spoil landscape. This diversity enhances the adaptive capacity of these sites. **[VH]**

A limit to their adaptive capacity is that regeneration of calaminarian grasslands would likely to be a slow process. The spoil and habitat characteristics are unique to each site, often forming densely packed micro-habitats and forming unique archaeological features. Even if the metallophyte species are able to recolonise sites, some value will be lost. **[VH]**

Suitable habitat for metallophytes is naturally fragmented, as it is only found around lead features. Even within suitable habitat, calaminarian grassland is often fragmented along the length of a vein, and is likely to have been broken up by agriculture. However, good connectivity is found with other grassland types in some areas, for example around Castleton. Better-connected sites will have higher potential adaptive capacity in terms of their living features. **[VH]**

Unlike the living features associated with lead mining features, the archaeological elements have no capacity for regeneration and should be considered a finite and non-renewable resource. Information and evidence contained in archaeological features will be lost if they are damaged or destroyed. **[VH]**

However, some degree of protection from change can be offered by environmental land management schemes. These are able to protect lead mining features (both biological and archaeological) if they have been identified during initial surveys. PDNPA-brokered agreements usually identify these. **[VH]**

In addition, 36 lead mining sites in the PDNP are designated as scheduled monuments. The Inventory of Regionally and Nationally Important Lead Mining Sites identifies 110 main sites that are nationally significant or regionally significant within the PDNP. As the Planning Authority, PDNPA will also have some control in protecting these sites from development, but they are very vulnerable to changes in farming practices. Environmental Impact Assessments or future equivalent regulations could apply, particularly to sites known to be regionally significant for archaeology and ecology. **[VH]**

Some calaminarian sites are afforded some protection from change by being designated as Special Areas of Conservation (SAC) in the PDNP: Gang Mine specifically for metallophyte vegetation, and as part of the designation of the Peak District Dales SAC. These sites are also Sites of Special Scientific Interest. **[VH]**

PDNP lead sites have been well studied by PDNPA and the Peak District Mines Historical Society (PDMHS). Management of mining legacy sites is often undertaken by non-professional organisations that have experience of mine conservation such as PDMHS and the Derbyshire Caving Association. Calaminarian grassland is less well studied but appears to need high pollution levels and an absence of management. **[VH]**

Key adaptation recommendations for lead mining features:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Ensure surveyed features are included in Historic Environment Records and Selected Heritage Inventory for Natural England (SHINE) datasets.
- Nurture collaborative networks to build capacity for monitoring (e.g. PDMHS, caving groups, other local interest groups).
- More research is required to better understand the hydrology of low flow river systems and their interaction with surface and underground workings.
- Liaise with other protected landscapes with similar phenomena to share knowledge and management techniques.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

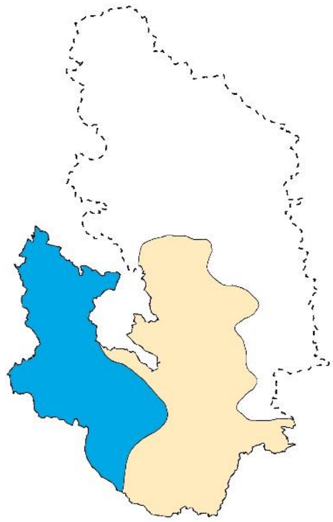
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Use existing records (e.g. Lead Legacy High Priority lead mining sites and landscapes) to target resources.
- Undertake regular monitoring, including at landscape scale, of selected sites to identify those sites likely to be most vulnerable in terms of archaeology and ecology.
- Put forward key sites for scheduling.

Lowland pastoral landscapes

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature(s) assessed:

- Lowland pastoral landscapes

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Undeveloped places of tranquillity and dark night skies within reach of millions

Feature description:

Much of the landscape of the White Peak and into the South West Peak can be classed as lowland pasture. In 2013, it was found that around 52% of the PDNP was permanent grass farmland.

The limestone dales of the White Peak have an exceptional biodiversity value and are home to many rare plants. See ‘Limestone grassland’ for the vulnerability assessment of these. However, the majority of White Peak pastureland is classed as ‘improved’ grassland and has a low diversity of plants and wildlife. Its main values are economic, cultural and aesthetic. The landscape provides grazing for livestock, and silage fields for dairy and beef cattle. In 2009 there were 65,974 dairy and beef cattle and 151,298 sheep present in the White Peak. Much of the White Peak area is enclosed by dry stone walls, which are a prominent feature of the landscape.

How vulnerable are lowland pastoral landscapes?

Lowland pastoral landscapes in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a vulnerable current condition and moderate adaptive capacity.

Lowland pastoral landscapes in the PNDP are vulnerable to changes in economic and political conditions, with agricultural intensification already affecting the historical character of many farms. One of the key potential impacts of climate change is a change in land use, particularly a turn to more arable usage with fields ploughed and remaining flower rich grasslands lost. Many small dairy farms have already been lost and been replaced by larger holdings with an increased demand for larger buildings and fields, together with fewer meadows and more fodder crops. However, sustainable and sensitive farming techniques could be implemented more widely to help offset some climate change impacts.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The pressures of modern land management and changes to the economics of farming in the UK has affected PDNP pastoral landscapes. In many cases this has driven intensification and consolidation of existing holdings.

Results from The Department for Environment, Food and Rural Affairs (DEFRA) 2010 census indicated that there had been significant changes within the dairy industry in the White Peak. The number of holdings had fallen from 242 in 2000 to 159 in 2009. Many small dairy farms that have gone out of business are now used for beef or sheep production, or have become part of larger dairy holdings.

Larger herds and flocks have led to an increase in the size of new agricultural buildings and an intensification of grassland management. The number of hay meadows has fallen, the number of silage fields has risen, and cultivation of land for fodder crops has increased.

This intensification has seen traditional buildings and boundaries removed to create larger fields. These features are key elements of the historic landscape character.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Human behaviour change

Wetter autumns and winters could result in an increased need for lambing to be taken indoors and a need for move livestock shelters. These new buildings could change the landscape character. Farming may shift from livestock towards arable because of increasing annual average temperatures and changing agricultural economics, leading to the ploughing and loss of permanent grasslands. Economic pressures on farming will continue to drive intensification and increase in farm size and could lead to farming decisions affecting large areas of landscape. [**H**]

An increase in flooding may mean some areas of pasture become unsuitable and are abandoned for at least part of the year. Pasture may be encroached by scrub in some areas. The traditional look could be lost if fields are left unmanaged. [**M**]

Higher summer temperatures could lead to welfare issues for livestock and increase the demand for structures such as tanks for storing water. Structures for shading or sheltering animals may become more common. Additions of this type could change the character of the landscape. [**M**]

A rise in visitor numbers in hotter drier summers may increase pressure on the infrastructure of the pastoral landscape with increased foot traffic particularly in honeypot areas. This may reduce the tranquillity at popular sites and at busy times of the year. **[H]**

Access to land may be impacted by wetter winters. If fields are wet, livestock may be required to spend more time indoors, reducing the opportunities for visitors to view spring lambs. Conversely, longer grass-growing seasons may also result in shorter periods indoors for housed livestock in well drained areas. **[M]**

Direct impacts of climate change

Rainfall changes could see increased drought impact on semi-natural habitats, especially grasslands on thin soils. Plants that are sensitive to drought may be lost, leading to changes in the composition of grasslands. If hay yields are impacted or the cutting times of the few remaining PDNP meadows has to change, that could have a negative impact on food production and farm income. In addition, wildlife associated with these habitats will continue to decline. Waterlogging of the ground could limit the operation of farm machinery and the movement of livestock. It could also result in the compaction of soils, while flooding may directly damage the plants and soil. **[H]**

Atmospheric composition changes coupled with increased annual average temperatures could lead to longer and more vigorous growing seasons for some plant species. Less competitive species may be reduced in abundance. A larger quantity of grass may be available for stock and silage production, but diversity of flora may decline further, leading to changes in landscape aesthetics. **[H]**

An increase in flooding or drought may mean green fields lose their current bright green look if underwater, are drying out or have turned brown. **[L]**

Invasive or other species interactions

Trees in field margins or hedgerows may be more at risk of being lost to disease from pathogens such as *Phytophthora* or ash dieback due to warmer, wetter winters. Already it is expected that 60-90% of ash trees will be lost due to this fungus. This could change the character of boundaries, wooded field edges and other small patches of trees. Livestock are at increased risk of disease such as bluetongue virus and rumen fluke infections, particularly if they are stressed due to other environmental factors. [**H**]

Sedimentation or erosion

Fields are shaped by the density of stock they contain. A rise in the numbers of livestock occurring in response to climate change could cause the increased erosion of fields. This is especially the case where stock are retained in the same location for extended periods. **[L]** An increase in the frequency and severity of storm events could increase flooding and surface run off and potentially leave some soils bare and reduced in nutrients. These processes could be detrimental to landscape aesthetics. **[L]**

What is the adaptive capacity of lowland pastoral landscapes? ***[Overall adaptive capacity rating: MODERATE]***

Lowland pasture land covers large and continuous areas across the White Peak and into the South West Peak **[H]**. Dairy, sheep, horses, and goat are all farmed, though sheep are the most abundant animal. Farms are owned by a variety of landowners. In 2009, there were a total of 890 holdings not counting those less than five hectares. **[H]** Grazed land is also found at a variety of different elevations within the 'lowland' landscape. This diversity in the types of animals grazed and locations in which grazing takes place increases the adaptive capacity of the feature.

Farmland can recover from damage or change, especially with help from landowners. Grasses grow quickly and bare soils can be re-seeded if necessary. Stone walls can be rebuilt and hedges can be repaired if damaged. However, the species diversity within these grasslands may be altered and decline further because of climate changes. **[M]**

Farming subsidies are currently paid for pastoral land. Livestock farming in the lowlands is generally more economically viable than upland farming and so is more likely continue. The PDNPA has stated its commitment to be a test-bed for future land management support packages which enhance the special qualities of the PDNP. **[M]**

Other institutional support comes from organisations such as the National Farmers Union who aim to ensure that UK farming remains viable. The diversity of ownership, farming types and economic resources is likely to enable climate change stressors to be partially offset in some places. **[M]**

Pasture farming in the PDNP has been practiced for millennia. Management changes can be undertaken to help offset some effects of climate change, for example by adjusting farming techniques to suit new conditions, both physical and economic if the necessary resources are available. [**M**]

Key adaptation recommendations for lowland pastoral landscapes:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Monitor the risk and spread of disease in both plants and animals.
- Reduce visitor pressure by encouraging use of the area at times outside of the high season.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.
- Explore opportunities for storing high levels of winter rainfall for use during the summer; these should be sensitive to the landscape.
- Encourage better connectivity in these landscapes.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- See the recommendations under ‘boundaries and patterns of enclosure’.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Enable more species rich hay cropping through meadow creation and restoration on a wide scale.
- Enable the diversification of plant species in permanent pasture; this will increase adaptive capacity to future change.
- Establish more trees and hedges in the landscape where appropriate to assist with surface water management, soil condition, and livestock summer shading. Help farmers to select the most appropriate and resilient species.
- Work to change perceptions about the value of ‘abandoned’ pastureland. More scrub and tree development on improved pasture would create a more sheltered and resilient overall landscape with microclimates that are more diverse, and improve future soil condition.

Managed moorland

Overall vulnerability rating:

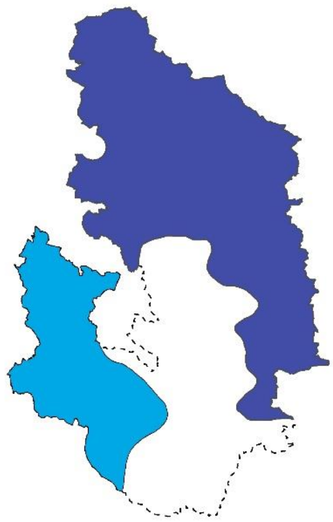
Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:

- Managed moorland

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry



Feature description:

Moorland refers to unenclosed land in the uplands made up of a mosaic of vegetation types including wet heath, dry heath and blanket bog. For the purposes of this assessment, managed moorlands refer to those managed via rough grazing and rotational burning. These managed moorlands cover several thousand hectares within the PDNP and are particularly prevalent along the eastern side of the Dark Peak.

These landscapes have been used by humans for thousands of years, from early post-glacial hunting and gathering to establishing settlements and agriculture when the climate allowed. Later when the climate made these areas uninhabitable they were used for livestock grazing. Since the early 19th century most open heather moorlands have also been managed for grouse shooting. Whilst shooting and grazing rights are held separately, the management of the land involves all tenants.

In addition, the peat and soils underneath these managed moorlands are valuable archives of information about their history, for example historic pollution or buried archaeology, and land use from prehistoric times to the present day.

How vulnerable is managed moorland?

Managed moorland in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, and a moderate adaptive capacity.

Managed moorland is in an insecure condition in the PDNP, subject to numerous pressures and often dependent on agricultural payment schemes. It will be particularly sensitive to increases in wildfire and changes in annual precipitation regimes. This is due to the huge detrimental impact that wildfire can have on these landscapes and the sensitivity of the plants to water availability. Managed moorland has some capacity to adapt, but is reliant on funding to facilitate this.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Farming sheep in the uplands is largely reliant on agricultural payment schemes without which it would be financially unviable. The planned changes in the emerging new Environmental Land Management Scheme (ELMS) ('public money for public good') may cause major changes to moorland management. Even without such changes, evidence shows a marked decline in the number of people employed in agriculture over the past decade alongside increasing diversification to support farm income.

Both heather beetle and *Phytophthora* are present in the PDNP. Heather beetle larvae feed on the leaves of heather stripping them bare. *Phytophthora* is a fungus-like organism, which causes damage to a wide variety of plants, with bilberry being of particular concern in moorland environments.

Red grouse are susceptible to *Cryptosporidium* 'bulgy eye', which has been present in the PDNP since 2010. Additionally, Louping ill is a tick borne viral disease present in England, which affects both sheep and grouse.

Until recently, hundreds of hectares of highly erodible bare peat covered some of these moorlands. While many of these areas have been revegetated, erosion channels still exist and some pockets of bare peat remain, making some areas unsuitable for sheep or grouse management. The peat of the PDNP is also highly contaminated from historic industrial pollution, containing high levels of heavy metals.

Traces of human activity on the moorland span the last 12,000 years, with the lower upland shelves and the high moorland fringes being key areas of activity. Moorland management itself has left its own archaeological signature.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Extreme events, such as heavy rain and severe wind may lead to greater erosion of soils and damage to underlying archaeology. Waterlogged ground could lead to changes in plant productivity and below ground biomass, for example root dieback due to anoxic conditions. These extreme events could cause altered community composition, making upland grazing and grouse moor management less suitable. **[H]**

Drier summers could result in increased fire risk, especially in heather dominated areas. In contrast, wetter winters could lead to drier heath and dwarf shrubs becoming waterlogged. Bracken may become more dominant due to these changes as it is highly competitive. Both of these climate change impacts could cause the loss of nesting and feeding habitat. This may reduce the suitability of some land for upland grazing and grouse moor management. **[H]**

Increased annual mean temperatures and warmer winters may result in dwarf shrubs becoming less dominant as more competitive and better-adapted plants become established. In some areas, mixed heath may be lost as it shifts to acid grassland or other habitat types. Management could move towards grazing rather than grouse shooting if heather moorland decreases. **[M]**

Wetter winters could result in increased nitrogen deposition resulting in habitat structure and composition changes. A reduction in the quality of heather may mean some areas are less suitable for grouse, meaning management for shooting becomes unsustainable. **[M]**

Other indirect climate change impacts

Extreme periods of drought coupled with heather moorland could potentially result in wildfire burning large areas of moorland and mixed heath. The loss of vegetation could cause an increase in peat erosion and damage to palaeoenvironmental information and buried archaeology. **[H]**

Warmer winters and summers risk the loss of dwarf shrubs, putting the habitat at risk as a minimum 25% cover is required to be classed as upland heath, a Biodiversity Action Plan (BAP) habitat. This habitat loss could lead to a decline in insect and bird communities. If a decline in grouse numbers occurred, it may no longer be viable to run shoots in some areas resulting in a change in management. **[M]**

Invasive or other species interactions

Warmer, wetter winters and drier summers may lead to increased damage from pest species, such as heather beetle, as well as an expansion of bracken to higher altitudes. These changes could lead to grouse moor management becoming less suitable in places, with a shift towards grazing if habitats change to grass dominated moorland. **[H]** Wetter winters could result in increased nitrogen deposition which in turn could result in heather becoming more sensitive to heather beetle outbreaks. As a result of pests, poorer quality heather may mean habitat becomes less suitable for grouse moor management. **[M]**

Human behaviour change

Drier summers could make moorland less productive for grazing. If the same grazing levels are maintained then areas could be overgrazed and become damaged. Furthermore, spring burning could become increasingly difficult if droughts mean that the risk of uncontrollable fire is too high. This may reduce the suitability of both upland grazing and grouse moor management in some areas. **Conversely** any increase in grazing could be detrimental to underlying archaeology but it can also help to keep down scrub and tree regeneration, helping to protect buried features. **[H]**

Hotter summers could result in increased visitor numbers. This in turn could lead to trampling of vegetation, increased erosion on popular routes, damage to buried archaeological features and increased disturbance of ground nesting birds, including grouse. Additionally, more visitors could result in higher wildfire risk. If such changes result in declining grouse numbers, shooting becomes less viable resulting in changes in management. **[M]**

Increased carbon dioxide levels and the resulting need for climate change mitigation may increase the demand for renewable energy installations. Such installations may be small scale for individual settlements or larger scale, such as wind farms. Increased demand for both tree establishment and small-scale hydropower on the moorland fringe is possible. Such installations may change the landscape character and possibly lead to management regime change as well as impacting upon buried archaeological features. **[M]**

Sedimentation or erosion

Wetter winters could lead to increased surface runoff and erosion of soil or peat. This is a particular risk as peat is already relatively thin in many areas. Once the peat has eroded down to the mineral surface underneath it is unlikely that moorland plants will colonise that area in the future, therefore these areas will not characteristically be moorlands. The root damage that this erosion could cause may lead to heather becoming increasingly sensitive to winter desiccation. Such changes may reduce the suitability of upland grazing and grouse moor management. Archaeological features of moorland management are also susceptible to soil erosion, especially on the moorland fringes where the evidence of transient prehistoric activity is greatest. **[H]**

Nutrient changes or environmental contamination

Higher temperatures alongside increased nitrogen deposition could increase grass productivity. This could lead to intensification of grazing causing both increased erosion and nutrient loading, changing the distribution and character of heather moorland. Management may shift towards grazing and away from shooting management in some areas. **[H]**

What is the adaptive capacity of managed moorland? *[Overall adaptive capacity rating: MODERATE]*

More diverse mixed heath areas are much more capable of adapting than large, heather dominated areas. Moorland is also relatively diverse and resilient along climatic gradients, as upland heath grades into lowland heath, montane heath and blanket bog. Low intensity management regimes that encourage more species diversity will likely be more resilient than intensively managed land with high stocking densities and homogeneous vegetation types. **[H]**

Large areas of upland heath and blanket bog with high topographic variability and spatial heterogeneity of habitats have an increased resilience. Mobile species, such as red grouse, are also more resilient. Due to the climatic gradient across the PDNP red grouse are more likely to persist for longer in the Dark Peak than the South West Peak. **[H]**

The relatively high growth rate of heather increases its resilience; however erosion lowers this capacity by reducing the seedbank. In contrast, peat's regenerative capacities are extremely low. Peat can erode by more than 3cm every year but only accumulates at a rate of 1mm per year. Current moorland restoration techniques, such as plug planting of dwarf shrubs, are currently used to revegetate sites where the seedbank is not sufficient. **[M]**

The economic viability of upland sheep farming is dependent upon agricultural payment schemes, reducing the industry's resilience. Driven grouse shooting and its associated management is currently economically viable, but its future looks uncertain. The current revegetation, rewetting and diversification underway to create a healthier blanket bog may help combat some stressors as the habitat becomes more resilient and aids in the protection of archaeology. **[M]**

The diversity of moorland ownership (for example water companies, National Trust and private estates) may support the offset of some climate change stressors. Furthermore, works aimed at improving the condition of degraded moorlands are underway by several organisations and private estates. These include Moors for the Future Partnership, National Trust and RSPB. **[M]** The restoration and rewetting of moorland may reduce the impact of drier summers and wetter winters through increased water retention and plant diversity. Greater shady areas in cloughs may also contribute to this due to tree establishment. **[M]**

Whilst conservation work aimed at improving the condition of moorlands is currently underway, the southerly location of the PDNP in the UK reduces its capacity to adapt. Additionally, there are disagreements surrounding future land use. While there is support for revegetating bare peat other changes may be more contentious between the various organisations in the future. **[M]**

Key adaptation recommendations for managed moorland:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Target re-creation and restoration around existing managed moorland areas to reduce edge effects and increase core area, reducing the effects of fragmentation.
- Adapt management intensity to the changing characteristics of the moorland.
- Explore the benefits of 'wilding' in areas where current management is dependent on payment through environmental land management schemes**.**
- Guide management strategies based on the carbon storage potential of peatlands.
- Ensure that cultural heritage is fully embedded in moorland management plans and the cultural complexity of moorlands is understood (See Buried soils, archaeological remains and deposits and Palaeoenvironmental remains and sequences for associated recommendations).

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Improve visitor management in areas of high wildfire risk by developing visitor management plans.
- Improve the knowledge of cultural heritage features to help target conservation efforts.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

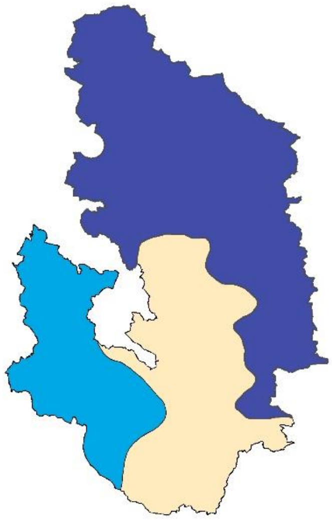
- Diversify single species dominated areas into mixed heath and bog. Encourage a mosaic of habitat types.
- Diversify land management techniques.

Prehistoric burial mounds and ceremonial monuments

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:



- Neolithic burial mounds - chambered cairn and long barrows
- Bronze Age burial mounds - barrows and cairns
- Stone circles
- Henges

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

This assessment focuses on Neolithic and Bronze Age burial features. However, many of the potential effects of climate change discussed will apply equally to other prehistoric ceremonial monument types such as henges.

There are currently 34 Neolithic and 238 Bronze Age burial mounds mapped in the PDNP, although the origins of a number of these are unclear and there are many more undated sites.

Neolithic chambered cairns typically consist of one or more stone chambers, covered by a mound of stones, into which human remains were placed.

Long barrows are almost always Neolithic in origin and typically consist of a long, roughly rectangular mound of soil or stone containing chambers for the ritual placement of human remains and other grave goods. Although, sometimes only the internal stone chamber survives. They are often located in prominent positions within the landscape.

Bronze Age barrows and cairns consist of a mound of earth or stones covering a central burial place, and there are numerous types and configurations to be found in the PDNP.

Gib Hill, adjacent to the Arbor Low henge in the White Peak is an important example of a Neolithic long barrow. At this site a round barrow was later added to the feature during the Bronze Age. The PDNP is home to several unusual sites with complex history such as the 210-metre-long Long Low site near Wetton.

The features types assessed here are all historically significant, and the PDNP contains some nationally rare and important examples. Collectively they show evidence of settlements and give some insight into how past ceremonies and rituals may have influenced modern day activities.

How vulnerable are prehistoric burial mounds and ceremonial monuments?

Prehistoric burial mounds and ceremonial monuments in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change, a variable current condition and a moderate adaptive capacity.

Prehistoric burial mounds and ceremonial monuments are in a vulnerable condition, with only half of those known intact. Climate change has the potential to accelerate damage to those structures remaining. Increased damage and attrition rates caused by expansion and contraction of stone and soil structures have the potential to play a role in the collapse of internal chambers. Increased visitor numbers in the PDNP, burrowing animals and future changes to farming practices may be some of the most important climate driven factors to impact these features. These features are an irreplaceable and finite resource, susceptible to damage and loss. However appropriate protections and management should be able to at least partially offset the impacts of climate change. Neolithic sites are likely to be the most vulnerable as an overall resource due to their rarity, while unscheduled and unknown sites will be vulnerable because appropriate management actions are less likely to be put in place.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Of the Neolithic burial mounds mapped in the PDNP, approximately half appear to be intact with the rest either being disturbed or reduced, and around 10% completely destroyed or removed. Information is scarce about those that are mutilated or badly cratered, and many of these will have undergone antiquarian excavations, which were poorly documented.

Nationally, many scheduled ancient monuments are at risk from arable agriculture associated with ploughing and are in declining condition. The predominately pastoral landscape means that to date this has been less of a problem in the PDNP. However, it is likely that some features are impacted by damage from plant growth or burrowing animals. The Heritage at Risk Register notes evidence of extensive badger burrowing in a bowl barrow in the Staffordshire Moorlands causing its condition to be classed as 'generally unsatisfactory with major localised problems'. It is very likely that other monuments in the PDNP face similar risks.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

It is possible that climate change will contribute to the damage or destruction of irreplaceable prehistoric burial mounds and ceremonial monuments in the PDNP.

Hotter summers and greater extremes of temperature have the potential to accelerate the attritional damage of monument structures through the increased thermal expansion and contraction of soil and stone. **[M]**

The shrink-swell action caused by repeated waterlogging and drying is likely to become more frequent during wetter winters and year-round storm events. This would increase the risk of the internal collapse of chambers within funerary monuments, leading to loss of irreplaceable archaeological information. Features located on clay-rich ground would be the most susceptible to this process. Due to their age, structures may be susceptible to direct erosion from increased hydraulic action. **[M]**

Human behaviour change

Hotter, drier summers are likely to attract more visitors to the PDNP, leading to an increase in footfall, off road vehicle and mountain bike use, and the possibility of an increase in vandalism. This may increase the erosion and damage of monuments and their surroundings. **[H]**

Combined climate effects may create the potential future need and opportunity for more intensive farming and a switch to arable in some places. The production of food or deep-rooted energy crops, the development of new farming infrastructure and the enlargement of fields could put features at risk from direct damage. Although land use changes may create opportunities for new discoveries to be made, these may go unrecorded. There is currently no robust system in place to report, manage and record such ad-hoc discoveries, so evidence may be lost. **[H]**

Changes to crops, grazing regimes and machinery may lead to a loss of groundcover on earthworks, especially on unprotected sites. **[M]** Increased frequency of winter storms and summer droughts may lead to changes in grazing levels as a result of changes in ground moisture. Drier conditions could lead to a reduction in cover of vegetation and wetter conditions may lead to an increase. If they were to become too wet, some sites may no longer be suitable for animals to graze. Both outcomes could have potentially damaging effects. **[L]**

Sedimentation or erosion

Increases in annual average temperatures may increase soil decomposition rates meaning that in places archaeological deposits may be revealed, leading to their damage or loss. **[M]**

Drought may lead to the reduction in cover of vegetation surrounding features, exposing the earth and making the area more vulnerable to erosion particularly during frequent or heavy rainfall periods. **[M]**

Invasive or other species interactions

Increased levels of atmospheric carbon dioxide and nitrogen may lead to increased growth rates in plants growing on or near sites. Species such as bracken, Japanese knotweed, Himalayan balsam and trees and shrubs have the potential to cause damage to earthworks and may require more management. **[M]**

Populations of burrowing mammals such as badgers, moles and rabbits have the potential to increase if warmer winters mean their natural mortality rate decreases. This could increase damage to buried archaeological deposits and destabilise buried stonework and structures. **[M]**

Other indirect climate change impacts

Hotter and drier summers, coupled with increased visitor numbers are likely to lead to an increase in incidence of wildfire on moorland and grassland. Removal of vegetation resulting from fire may leave the structure and surrounding areas vulnerable to the risk of erosion from animals and weather. Damage may also occur to the monument from the firefighting activity itself. **[H]**

Nutrient changes or environmental contamination

Possible soil chemistry alterations as a result of atmospheric pollution may lead to the damage of ceremonial monuments sensitive to these changes. **[L]**

What is the adaptive capacity of prehistoric burial mounds and ceremonial monuments?

[Overall adaptive capacity rating: MODERATE]

Some protection is provided by the Ancient Monuments and Archaeological Areas Act of 1979 for scheduled sites, which can reduce damage and changes to sites caused by farming practices such as ploughing. Unfortunately, this protection is not afforded to undesignated or unknown archaeological sites, and indeed 95% of PDNP heritage assets hold no formal protection. Many of the known barrows and cairns in the PDNP are scheduled, but the PDNPA barrow survey indicates that many are not. At scheduled sites, there is an increased probability of appropriate management actions being implemented to offset climate change impacts. [H]

Some funding from sources such as Historic England Management Agreements, the National Lottery Heritage Fund and Environmental Stewardship Agreements is currently available, but is limited. Monuments are likely to have a variable uptake of these funds and the status and designation of sites is likely to affect the amount of funding received. It is more likely that designated sites will obtain funding over undesignated ones. [H]

There is a good level of information and skill available to undertake adaptation to at least partially deal with the indirect impacts of climate change through careful management of sites, with bodies such as Historic England and PDNPA providing advice and information. [M]

Prehistoric burial mounds and ceremonial monuments and associated archaeological artefacts are an irreplaceable and finite resource, susceptible to damage and loss. However, appropriate protections and management should be able to offset partially the impacts of climate change. [M]

Bronze Age sites in the PDNP can be found in a wide variety of locations with different geologies, land uses and habitats. This diversity will provide a degree of protection to the overall resource. However, there is less diversity in known Neolithic sites due the small number discovered, and these are likely to have less adaptive capacity as an overall resource. [L]

Key adaptation recommendations for prehistoric ceremonial monuments:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Create an action plan for recording sites discovered as a result of land use changes and other factors.
- Consider the landscape context of these structures and improve resilience of the surrounding landscape to better protect them.
- Ensure that any climate adaptations can be reversed to prevent long term impacts on features.
- Use sites themselves as valuable assets for example to sustainably generate money for their upkeep. Explore opportunities in future environmental land management schemes.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

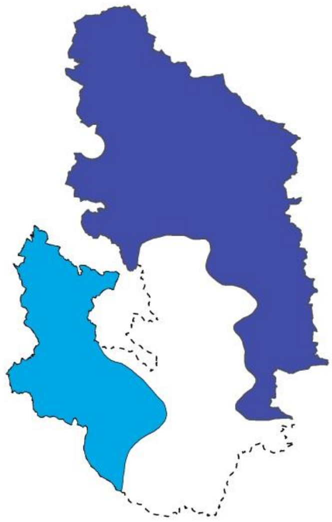
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Further exploration into evaluating site significance and evaluating which known assets require protection and management.
- Implement monitoring of sites, especially where adaptations have been made and their surroundings - this may provide beneficial information for other sites. Carry out regular monitoring of scheduled sites.
- Put forward non-scheduled sites of suitable quality for scheduling.

Prehistoric and Romano-British settlements, field systems and cairnfields

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Prehistoric and Romano-British settlements, field systems and cairnfields

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

Prehistoric and Romano-British settlements, field systems and cairnfields give us an insight into what life and agriculture were like in the distant past. These archaeological features have been revealed through the National Mapping Programme (NMP) and extensive archaeological survey over decades within the PDNP. Arable cultivation, particularly in areas with free-draining soils, has revealed pre-medieval settlements and land uses. The PDNPA has completed a large amount of survey work to discover further examples of these archaeological features. This includes 36 records of prehistoric settlements, 36 records of Romano-British settlements, and 65 records of prehistoric cairnfields. In Northern England some of the largest and best preserved prehistoric settlement, field system and cairnfield sites are found on the Eastern Moors of the PDNP.

How vulnerable are prehistoric and Romano-British settlements, field systems and cairnfields?

Prehistoric and Romano-British settlements, field systems and cairnfields in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, coupled with a varying current condition, and a moderate adaptive capacity.

The current condition of all features is unknown as many have yet to be discovered, but of those that are known only 13% are in poor condition. Sites may be vulnerable to climate change following changes in farming practices, direct erosion and erosion of the soils around the features, and further growth of nuisance plant species. There are appropriate management and conservation actions to help these features adapt to climate change, however it is expected that a significant proportion of these sites have not been formally designated and therefore adaptations are less likely be put in place.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

Of the sites that the PDNPA has noted, detailed above, 16% have been excavated and 23% are of uncertain provenance or function. 13% have been damaged, destroyed or lost.

Thus far, human activities have had the most significant detrimental impact on these features. Farmers and landowners have often destroyed or damaged sites if their significance was not recognised. The ploughing of fields in recent centuries has led to the destruction of this surface evidence of human activity.

Past changes in climate have helped to protect some sites from human interference. Upland settlements which were abandoned when the climate became inhospitable may not been intensively farmed since and archaeological evidence has therefore survived.

Growth of nuisance and invasive species and animal burrowing have already had harmful effects on some prehistoric and Romano-British settlements, field systems and cairnfields. At time of writing, the Heritage at Risk register shows there are two 'at risk' sites in the PDNP. One is the Callow prehistoric settlement and field system on Carr Head Moor where bracken, scrub and trees are putting the feature at risk due to under grazing. The North Lees Countryside Stewardship Scheme is now addressing this. The other 'at risk' site is Cowell Flat, which is a prehistoric field system that faces similar plant growth issues. Other similar sites in the PDNP are known to face the same problem.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Direct impacts of climate change

Most impacts from climate change affect prehistoric and Romano-British settlements, field systems and cairnfields indirectly. Directly, precipitation patterns and temperature may have an impact through erosion of the features. Exposed structures may become damaged or weakened due to changes in the wetting and drying cycle or an increase in hydraulic action [**H**]. Structures affected by thermal expansion may be damaged by greater extremes of temperature, causing accelerated erosion of these features. [**M**]

Human behaviour change

Human responses to climate changes are expected to have the biggest impact on these features in the future. There may be landscape use changes as a result of climate change such as more intensive farming, the use of deep-rooted energy crops, establishment of woodlands, and new building developments. This may put prehistoric settlements and field systems at risk. Changes to how moorlands are managed will also affect these sites which are often on the lower moorland ledges. Rewilding could pose a particular threat. [**M**]

An increased frequency of winter storm and summer drought events may result in changes to ground cover. This is because use and management of sites, irrigation and drainage practice, and farming practices may all change. [**M**]

The difference in vegetation cover could lead to changes in grazing levels. If the ground became drier then vegetation cover may decrease and grazing could be reduced, and grazing could increase if the ground was wetter and there was more vegetation growth. Grazing would only increase up to a point however, if it was too wet then animals would have to be removed. Both outcomes are potentially damaging to these features, either directly or resulting in uncontrolled vegetation growth. [M]

A change in ground conditions could also encourage new crops to be grown. This could cause, or could happen alongside, a drying of waterlogged environments such as peat soils. Peat soils may dry out and become oxidised causing the loss of historic field patterns. [M]

Where excavations are taking place, an increase in storm and flood events may cause delays and therefore damage of these exposed sites. This is especially the case on clay and other slow draining geologies. [H]

Hotter, drier summers are likely to attract more visitors to the PDNP. This may cause damage to these features through increased erosion from footfall. [M]

Land use changes as described above may lead to new sites being revealed which could benefit these features or put them at risk. If the locations of the features are known then protections can be put in place decreasing the chances of future accidental damage. However, features may be damaged during discovery and not subsequently reported and recorded appropriately. [M]

Hotter, drier summers resulting in droughts may provide opportunities for new discoveries in ways that help to protect these features. Marks can appear in crops or as parch marks or lusher growth in grass, highlighting where buried stone walls, foundations or deeper, moisture-retaining ditches are located underground. This occurs because the soil has a different depth or quality over the buried remains, causing patterns to appear on the surface. This helps to discover new heritage assets that can be mapped without damaging the sites themselves. [H]

Invasive or other species interactions

Warmer, wetter winters and hotter, drier summers may result in higher populations of burrowing animals such as badgers, moles and rabbits. They may also increase the growth of nuisance species such as bracken and deep rooted plants. This can damage or completely destroy evidence of prehistoric settlements and field systems. There has already been evidence of this at Cowell Flat and Carr Head Moor as described above in 'Current Condition'. [H]

Nutrient changes or environmental contamination

Atmospheric pollution may damage settlements and field systems located at sites sensitive to soil chemistry changes. [L] Soil chemistry could also be changed due to increased incidences of drought, fire and flooding, potentially damaging sites further. [M]

Sedimentation or erosion

Drought, fire and flooding increases could lead to erosion occurring. This erosion could cause direct damage as referenced above in 'Direct' or could cause erosion of the area around these features, causing structural damage to features such as field banks and other archaeological remains. [M]

What is the adaptive capacity of prehistoric settlements and field systems?

[Overall adaptive capacity rating: MODERATE]

The known field systems and cairnfields are protected by designation under the Ancient Monuments and Archaeological Areas Act of 1979, which aims to prevent damage occurring from farming practices and other activities. Existing practices, at the time of scheduling, are sometimes allowed to continue. This protection does not apply to 95% of the PDNP heritage assets as they are non-designated and unknown sites. The PDNPA is aiming to identify and access sites of these archaeological resources so their significance can be recognised and measures put in place to protect them. Examples of the most vulnerable designated sites can be found on the Heritage at Risk register, but many more vulnerable sites are not included. **[H]**

At scheduled sites, management actions are more likely to be put in place. These may be able to partly offset damage from climate change stressors. The status and designation of a site should help determine the management techniques to be put in place. Designated sites may be more likely to receive funding and appropriate management, which leaves undesignated sites more vulnerable. Funding may include Historic England Management Agreements, Countryside Stewardship and the National Heritage Lottery Fund. However, access to these funding options is limited and the uptake on private land is likely to be variable. **[H]**

Prehistoric and Romano-British settlements, field systems and cairnfields are not able to 'recover' by themselves and cannot regenerate. They are a finite resource vulnerable to loss and damage. There are appropriate management and conservation actions that can help these features and the PDNPA and Historic England provide advice regarding appropriate adaptation actions. **[M]**

In the PDNP, there are a large number of prehistoric settlements, field systems and cairnfields found in locations with different geologies, habitats and land uses. This diversity in location helps to spread the risk of damage from climate change. **[M]**

Key adaptation recommendations for prehistoric and Romano-British settlements, field systems and cairnfields:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Continue to stabilise peat and soils to prevent erosion.
- Continue assessing site significance in order to increase knowledge of asset existence to determine which need protecting.
- Facilitate data sharing information between organisations that helps us understand the extent of archaeological features. This will help inform future adaptation planning.
- Use sites themselves as valuable assets for example to sustainably generate money for their upkeep. Explore opportunities in future environmental land management schemes.
- Ensure that any climate adaptations can be reversed to prevent long term impacts on features.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

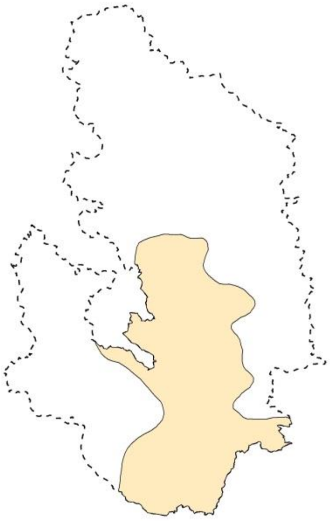
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Carry out regular monitoring of scheduled sites.
- Put forward non-scheduled sites of suitable quality for scheduling.
- Consider locations of important prehistoric and Romano-British settlements, field systems and cairnfield sites when planning flood management, tree establishment, or piloting wilding trial schemes.
- Monitor outcomes of any adaptations that are implemented.

Villages associated with medieval strip fields

Overall vulnerability rating:

Very low	Low	**Moderate**	High	Very High



Feature(s) assessed:

- Villages associated with medieval strip fields from C10th

Special qualities:

- Characteristic settlements with strong communities and traditions

Feature description:

Villages associated with medieval strip fields tend to be found in the White Peak. This historic landscape is characterised by its repeated pattern of narrow strip fields - usually medieval open fields which have later been enclosed. These tend to surround villages made up of limestone buildings with traditional vernacular architecture and distinctive regional styles.

While some medieval strip fields have already been lost - some 'fossilised' strips (i.e. walled strips which preserve the layout of the open field) still remain, as many have been converted to pasture.

The types that are most visible and generally are surrounded by dry stone walls, although some are enclosed by hedgerows particularly on lower slopes. The fields often overlay surviving examples of ridge and furrow - an archaeological pattern created by a system of ploughing used during the Middle Ages.

This assessment focusses mainly on the impact of climate change on medieval strip fields, and therefore on associated villages. For an assessment of the effects of climate change on physical village infrastructure, see ‘Building materials’.

How vulnerable are villages associated with medieval strip fields?

Villages associated with medieval strip fields in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, a relatively stable current condition, and a moderate adaptive capacity.

To date the dominance of pasture and lower intensity livestock farming in the PDNP has been a factor in the preservation of this feature. Strip fields are vulnerable to farming intensification in response to climate change, especially a change from pasture to arable land use.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

Many medieval strip fields expressed as ridge and furrow are likely to have already been lost to the modern plough – but some fossilised strips remain. The dominance of pasture in the PDNP over arable farming has been an important factor in the preservation of these strips.

However, medieval strip fields (and therefore the villages which are associated with them) are vulnerable to farming intensification and it is assumed that at least some of these remains have been lost in more recent years due to changes in agriculture, although no evidence for this was able to be located for this assessment.

Examples of fossilised strip fields can be found in the villages of Wardlow, Chelmorton, Flagg and Monyash but also in Longnor, Tissington, Bradbourne, Edensor and Tideswell.

Most sites are not subject to any formal protection although there are some protection measures offered through Countryside Stewardship and the Environment Impact Assessment Regulations 2017 and the Hedgerows Regulations 1997.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Direct impacts of climate change

An increase in the frequency or severity of flooding may reduce pasture growth and result in the loss of hay and silage harvests. Additional costs may then be incurred from pasture reseeding having to buy in extra feed and having to pay for additional slurry disposal if livestock have to be housed for longer than usual. This could then make the pasture system uneconomic and lead to changes that no long preserve the field system. **[M]**

Wetter winters could lead to waterlogging, and where ridge and furrow patterns remain there may be a risk that erosion will be accelerated. This may be further impacted by more frequent and extreme droughts that may reduce ground cover and further increase erosion. The risk level also depends on vehicle movements on a site and the stock levels (and therefore poaching of the ground). **[H]**

Human behaviour change

Wetter winters are likely to mean an increase in demand for modern housing for livestock. The landscape around villages is sensitive and the addition of modern barns may change the traditional look of fossilised strip fields and the character of the villages. **[M]**

The character of the landscape around villages may be sensitive to installation of renewable energy sources such as wind turbines or solar panels. An increase in demand for such climate change mitigation measures may also mean the traditional look and character of the villages is changed. **[L]**

Hotter summers, warmer winters and other combined factors including precipitation change may mean that pasture could also be converted to arable usage if it is deemed to be economically worthwhile. Fossilised strip fields have survived because many were converted to pasture but if they were to be enlarged or ploughed many features would be lost completely or reduced. However, it should be noted that agricultural economics will be subject to many variables other than climate change. **[L]**

Invasive or other species interactions

In wetter warmer winters any changes to grazing regimes could see a rise in the growth of invasive and nuisance species changing the character and traditional look of fossilised strip fields. It should also be noted that that biodiversity value of the current pastoral landscape of the PDNP is generally very poor. **[L]**

Changes in temperature, particularly wetter warmer winters may see an increased occurrence of disease such as liver fluke, intermediate disease host species such as mud snails, and also emerging diseases that are spread by insects such as the blue tongue virus. Not only could these potentially lead to costly disease outbreaks but a rise in pests, diseases and mycotoxins (produced by fungi) could adversely impact the quality of livestock feed available. Resulting changes to agricultural economics could see a decline in the pastoral system which has preserved this feature. **[L]**

Other indirect climate change impacts

Extreme drought conditions and increased visitor numbers could see a rise in the incidence of wildfire. Longer grass could be susceptible, leading to bare ground and ridge and furrow being more easily eroded. However, as there are very few places in the PDNP where fields are managed as meadows the risk is minimal at least in the short term - so this is unlikely to have any meaningful impact that would change its structure, function or extent of this feature. **[L]**

Where clay rich soil is present, the ground is particularly sensitive to the shrink-swell action with the British Geological Survey describing it as 'the most damaging geohazard in Britain today'. This could have direct effects not only on farmed land but on villages surrounding strip fields (see also 'Building Materials').

What is the adaptive capacity of villages associated with medieval strip fields?

[Overall adaptive capacity rating: MODERATE]

In the majority of cases planning permission is needed to make changes to agricultural land or commercial property however walls are provided little protection and in general boundary protection is poor. Changes will still occur if keeping livestock on pasture becomes economically unviable and this feature is vulnerable to the amalgamation of fields. Hedgerows Regulations currently apply for strip fields fossilised by hedgerow enclosure – and these may qualify as 'important' hedges, although exceptions can apply meaning that some hedges may be able to be removed without control. **[H]**

Fossilised strip fields marked by dry stone walls (primarily on the limestone plateau) are more resistant than those marked by hedges, as the latter are more likely to be removed or be in decline through lack of sympathetic maintenance. However, areas of ridge and furrow are more likely to survive on the thicker shale soils than the thinner soils on the limestone plateau. **[M]**

The majority of PDNP villages with medieval strip fields are found on the limestone plateau although they can also be found in several other places including the Peak Fringe areas. Although they exist on a variety of soil types, the landscape is fairly comparable in character, so similar exposures and impacts will be felt anywhere in the region. **[M]**

It is likely some funding options will be available for maintaining landscape through Countryside Stewardship - however these are limited and the future of this scheme is uncertain at present. The current trend is that land in the NP within an agreement is declining. The PDNPA also has a scheme for traditional boundaries. **[L]**

As there is diversity in land ownership, management, information and skills available to adapt and conserve the landscape it is therefore likely that some features will survive whilst some will decline. **[L]**

Key adaptation recommendations for villages associated with medieval strip fields:

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Ensure conservation area boundaries and appraisals include relevant fieldscape setting when they are revised.
- Use sites themselves as valuable assets for example to sustainably generate money for their upkeep. Explore opportunities in future environmental land management schemes.
- Consider reducing or maintaining low stocking levels in fields with archaeological sensitivity.
- Consider slot-seeding rather than ploughing and re-seeding where appropriate, to avoid degradation of the landform in fields with archaeological sensitivity.

Geology, geomorphology and soils

	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Buried soils, archaeological remains and deposits	High	Moderate	**High**	168
Healthy soil	High	Moderate	**High**	173
High open moorland and edges	High	Moderate	**High**	178
Limestone dales	High	Moderate	**High**	183
Palaeoenvironmental remains and sequences	High	Moderate	**High**	188
River valleys	High	High	**Moderate**	193
Show caves and caverns	Moderate	Moderate	**Moderate**	198
Slopes and valleys with woodland	High	Moderate	**High**	203

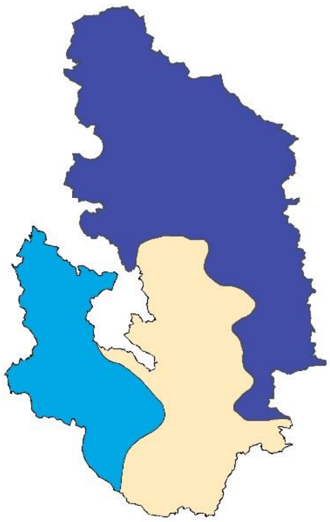
Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

Buried soils, archaeological remains and deposits

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:



- Buried soils, archaeological remains and deposits

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

Buried soils are soils that lie beneath later sediment. They are found under natural deposits or human-made deposits and structures.

They are an important source of archaeological information as they represent former ground surfaces or past human activity.

Archaeological remains tell us about the past and give an insight into human life and development. Remains can include a wide range of human-made items including tools, weapons and even fragments of clothing. For an assessment of biological deposits, see section ‘Palaeoenvironmental remains and sequences’ and for an assessment of present day soil, see section ‘Healthy soil’.

How vulnerable are buried soils, archaeological remains and deposits?

Buried soils, archaeological remains and deposits in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables. Their current overall condition is difficult to ascertain, but they have a moderate adaptive capacity.

One of the key potential impacts to archaeological remains is drier summers and wetter winters which could cause direct damage and also change how the land is used. Previous drainage of bogs and other soils coupled with development, farming practices including ploughing have caused damaged these features already. Archaeological remains cannot recover once they are lost. Although work is taking place to restore PDNP wetlands, this is reliant on funding being available.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The condition of buried soils and archaeological remains is difficult to ascertain, as there are many that are still to be discovered; however there are factors known that help highlight areas at greatest risk.

The survival of archaeological remains and deposits is dependent on the environment into which it was originally buried. It has been found that certain materials are better preserved in acidic environments while others are better preserved in alkaline environments.

In the Dark and South West Peak for example, peat bogs are a very important due to their value in preserving buried archaeology. This is because numerous materials survive better in anoxic environments i.e. those without oxygen. The waterlogged nature of these bogs means that the majority of soil microorganisms along with fungi are not able to operate as decomposers.

Unfortunately, PDNP peat bogs are generally in an extremely poor condition with a low or erratic water table (see assessment of 'Blanket Bog') which means it is likely that some items have already been lost or degraded. Previous human drainage of bogs and other soils across the PDNP will have already degraded or destroyed buried soils and some archaeological deposits. In addition, ploughing, development and other farming practices are very likely to have affected the condition of these features.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Buried soils and archaeological remains could be significantly impacted by climate change. Increased surface water run-off in extreme storm events could see peatlands damaged and hydrology impaired as gullies are formed and widened, putting archaeology at risk. River valleys at risk of flooding could also experience a significant impact on archaeological remains. There may be changes to the water table or degradation of riparian habitats. Extreme rainfall and flooding could also cause erosion to underground mines, spoil heaps from lead mining, and steep earthworks. **[H]**

Drier summers could also have a significant impact on sites with good organic preservation. Drying of soils may increase the cracking of the surface allowing oxygen to enter the subsurface region and increase microbial action activity and oxidation of materials. In addition, the cycle of wetter winters and drier summers will cause further damage to waterlogged archaeological deposits. In PDNP peat soils in particular these changes could see the destruction of organic remains. **[H]**

Increased annual temperatures could also accelerate microbiological activity that could lead to the destruction or degradation of organic remains that are sensitive to such change. **[M]**

Human behaviour change

Drier summers could lead to changes in the economics of upland farming. For example, drier heathlands become more suitable for intensive management and grazing regimes may be changed. Erosion may be increased by overgrazing and high stocking levels, damaging remains and deposits. Agricultural improvement may lead to changes in soil chemistry - such as pH. This could affect preservation of materials. **[H]**

Temperature changes leading to longer growing seasons could see new types of crops planted and marginal farming areas becoming more viable. Pasture converted to arable crops and associated ploughing and drainage may disturb soil layers while physical buried remains could be damaged. **[H]**

Increased pressure for construction of renewable energy installations such as wind turbines, particularly on exposed areas, could affect the feature, as soils will be sensitive to installation of equipment, compaction and disturbance. This may cause an increase in erosion and change the hydrology or an area leading to drying of the site. However, current planning policies make renewable energy installations such as wind turbines on PDNP moorlands less likely. **[M]**

Invasive or other species interactions

If warmer winters lead to higher populations of burrowing mammals such as badgers, moles and rabbits buried archaeological deposits could be disturbed and hydrology of the area in question could be changed, with drier sites leading to less preservation of organic materials. **[M]**

Buried archaeological deposits could be sensitive to more rapid scrub and tree colonisation as a result of increases in atmospheric carbon dioxide and nitrogen levels and increased average annual temperatures. Not only can they be disturbed directly by root systems, but an increase in evapotranspiration could lead to drying of some sites. **[L]**

The fragile surface of damaged bogs is sensitive to increased erosion if winter storm events increase in frequency and intensity. In other habitats the areas where trees are uprooted and remains are therefore exposed or damaged could increase. Erosion may lead to more opportunities for invasive species to colonise, potentially drying soils further and increasing the risk of damage to remains and deposits. **[L]**

Nutrient changes or environmental contamination

Atmospheric changes that result in the chemical composition of water being altered could have an impact on the anoxic environment where it depends on microorganisms that are sensitive to such changes in water chemistry. If this environment is not maintained some remains may be lost or damaged. **[H]**

Sedimentation or erosion

Degraded bogs in particular are sensitive to erosion, so an increase in summer droughts and winter storms could result in bare peat damaged by water and wind. This also applies to other soils across the PDNP. However, the deposition of eroded sediment could protect other sites. For example, while some archaeology could be exposed by increased erosion, some could also be buried further by the silt and material that has been moved. The uncovering of new sites and materials through increased erosion should only be considered a positive result of climate change if there is resource to record the new information - exposure is more likely to see the new sites damaged or lost. If erosion rates increase, remains and deposits may also be exposed to oxygen as the water table falls. **[H]**

Other indirect climate change impacts

Drought and drier ground conditions could lead to an increased incidence of wildfire in the PDNP, particularly on degraded bog and heath sites. Potentially large areas of peat and vegetation could be lost further increasing erosion and peat loss. In such conditions dry peat also becomes more susceptible to damage from managed burns and there is more potential for them to get out of control. Fire can damage archaeological features within or below the peat and mean they are lost or severely affected. Efforts to manage fire risk could also impact archaeological features and deposits, for example flail cutting of firebreaks. Even if care is taken to avoid such features to minimise the risk of damage, this in itself may makes them more vulnerable to wildfire damage, as they are surrounded by fuel. **[H]**

What is the adaptive capacity of buried soils, archaeological remains and deposits? *[Overall adaptive capacity rating: MODERATE]*

All archaeological remains, deposits and features are unable to recover or regenerate from damage, so have a low adaptive capacity in this respect. **[VH]**

Although they can be found across the PDNP in a wide diversity of locations, some of the most sensitive places are probably the waterlogged peatlands. Because these are hidden features, it is unknown exactly where important remains can be found lowering the capacity for human adaptation measures to be implemented. **[M]**

Some money from grants and partners is available for peatland restoration activities, but there is currently a decrease in the uptake of agri-environment schemes in the PDNP. The future of agricultural subsidies after the UK's exit from the European Union is currently very uncertain. Archaeological deposits, apart from those in peat, are at risk because they often do not have sources of funding available to secure the habitat in which they are situated and the vast majority have no form of statutory protection. Those areas that do not come under planning control and do not have funding sources available to secure them outside of agri-environment schemes will be some of the least adaptable. **[H]**

There are several organisations in existence that are able to carry out or oversee peatland and other habitat restoration projects in the area, in order to help safeguard these features. Organisations include Moors for the Future Partnership, National Trust, Royal Society for the Protection of Birds and South West Peak Partnership. These increase the capacity for adaptive measures such as habitat restoration to be taken. However, only a small proportion of the park is in public ownership and the involvement of private landowners taking advantage of current land enhancement opportunities will be mixed in uptake and extent**. [H]**

Information and expertise is available from the organisations highlighted above and others including Historic England and PDNPA Planning and Cultural Heritage teams. **[L]**

Key adaptation recommendations for buried soils, archaeological remains and deposits:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Habitat enhancement to stabilise the water table, which will create stable environmental conditions for preserving remains and deposits.
- Integrate heritage protection into moorland restoration schemes.
- Appropriate management of the overlying habitat to prevent/minimise indirect damage from e.g. erosion, wildfire, root disturbance due to scrub growth or increased burrowing animal activity.
- Phase out burning on blanket bog. Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Investigate funding for strategic survey to locate and catalogue sites of archaeological interest and potential (deposit modelling) in order to identify where habitat enhancement or management needs to take place to protect buried archaeology.

Healthy soil

Overall vulnerability rating:

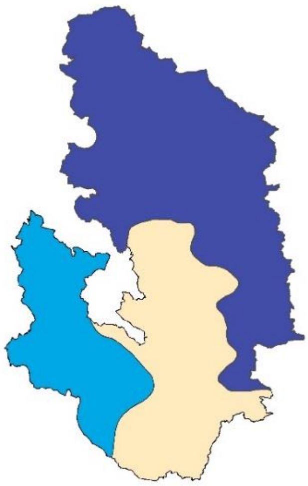
Very low	Low	Moderate	High	Very High

Feature assessed:

- Healthy soil

Special qualities:

- Vital benefits for millions of people that flow beyond the landscape boundary



Feature description:

The PDNP contains varied soil types. In the Dark Peak blanket bog, peat soils are fringed with acidic loamy soils, often with a wet peaty surface. The White Peak has predominately slightly acid but base-rich loamy soils, with some areas of shallow lime-rich soils over limestone. The South West Peak contains a mixture of soils, including blanket peat and seasonally wet, acidic loamy and clay soils. For assessments of related subjects, see 'Blanket bog', 'Buried archaeological soils and deposits', and 'Palaeoenvironmental remains and sequences'.

Healthy soils are a living system and provide many important ecosystem services. They are an important store of carbon, vital for biodiversity, water quality and the agricultural economy of the PDNP.

How vulnerable is healthy soil?

Healthy soil has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a varied current condition, and a moderate adaptive capacity.

Soil health in the PDNP is likely to have followed the general nationwide decline over the past 50 years, with Dark Peak peat soils being in the worst condition. Erosion caused by extreme droughts and storms are one of the major potential impacts on healthy soils. A change in soil moisture levels and chemistry have the potential for a significant impact on soil biota and therefore health.

While some soils can recover without intervention, most will require active management steps to be taken. Replenishing organic matter and making radical changes to landscape level management including the creation of woodland, scrub and diverse flower-rich meadows would increase the adaptive capacity of soils.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

In England and Wales in recent decades there has been a loss of soil organic carbon. This is due to changes in land use and management. Intensification of arable agriculture has been an important driving factor in this national loss. While this farming type is relatively uncommon in the PDNP, the intensification of agricultural in general has had a negative effect in soil health since the Second World War. The conversion of semi-natural to agriculturally 'improved' grassland, the loss of hay meadows, the creation of conifer plantations and the increased use of fertilisers are just some of the contributory factors.

In addition, the peat soils in the Dark Peak are in a particularly poor condition. Pollution from the industrial revolution has had a major impact stripping vegetation and leaving large areas of bare peat exposed. Much of this area is still heavily contaminated and acidified. This soil type has also suffered from extensive erosion, with deep gullies present.

However, there have been agri-environment schemes that can contribute to the management of soil carbon. In 2016, 78 percent of the PDNP was covered by such schemes, although this figure is now significantly lower .

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Sedimentation or erosion

Climate change could have a significant impact on the health of soils across the PDNP. Periods of drought during hotter, drier summers could lower the water table significantly and potentially alter its hydrological behaviour for long periods. This could lead to increased erosion of dry soils, peat oxidation and carbon loss. **[H]** Drier summers could also inhibit carbon storage and increase soil loss during rainfall events, as well as an increase the risk of wildfire.

Wetter winter conditions could also lead to increased erosion - rivers may be realigned and there may be changes to slope and soil stability. Greater amounts of sediment may enter watercourses and soil fertility is likely to be reduced. **[H]** An increase in storm event intensity and frequency could cause a rise in dissolved organic compound levels in waterbodies that require water treatment, the silting up of reservoirs and negative effects on aquatic habitats. **[H]**

Direct impacts of climate change

Soil health will be sensitive to changes in water content - both from drier summers or increased winter precipitation. Not only could this change the soil habitat and biota – i.e. the organisms living within the soil - but also the chemical content of water siting within the soils. This could lead to a short-term release of carbon dioxide and have long-term effects on carbon sequestration, and temporary effects on the appearance of the landscape. These changes could lead to a reduction in abundance of earthworms and other soil invertebrates, could alter soil fertility and vegetation cover, and increase the risk of soil becoming compacted. **[H]**

An increase in intense rainfall events may lead to the loss of more topsoil and nutrients due to erosion. Where this occurs, vegetation is likely to be slower to recover. **[H]**

Hotter summer soil temperatures could speed nutrient cycling and increase the release of nitrogen and carbon into the atmosphere. Following dry summers there may also be a delay in re-vegetation. **[M]**

Soil structure and chemistry is sensitive to atmospheric composition. Further increases in carbon dioxide and nitrogen compounds and the resulting acidification of the soil may affect plant growth and water quality by mobilising minerals or heavy metals. The already acid soils of the Dark and South West Peak are likely to be more vulnerable than the more neutral or alkaline soils of the White Peak. **[L]**

Other indirect climate change impacts

An increase in wildfire due to hotter, drier summers and longer periods of drought, coupled with a rise in visitor numbers as an ignition source may lead to increased erosion and damage to soil health. Heathland and degraded bog habitats are likely to be most vulnerable. **[H]**

Human behaviour change

Hotter, drier summers could see the loss of pastoral farming and a move towards cultivating arable crops in areas with higher soil fertility such as the White Peak. This could leading to the removal of boundaries to create larger fields, the removal of trees and an increase in the use of large agricultural machinery creating soil compaction. A rise in tourist numbers during hot summers could see increased trampling and compaction of soils at certain sites. **[M]**

Soils and their vegetation cover are sensitive to changes in soil moisture. Drier summers and wetter winters could affect crop yields, leading to a change in the type of crops planted or livestock chosen. An increased demand for water resources would be likely, potentially lowering the water table in places. **[M]**

Invasive or other species interactions

Increased temperature and water table changes leading to changes in soil nutrient availability could affects the ability for invasive and nuisance species to colonise or dominate new areas. This would be likely to have a negative impact on the soil biota and structure. It could also lead to changes in existing vegetation, for example, heather growth on blanket bog was significantly affected by the 2018 drought, and invasion by grass species into such habitats may be likely. **[M]** Changes in soil moisture could also play an important role in determining the severity of future plant disease epidemics. **[M]**

Nutrient changes or environmental contamination

Increased winter rainfall and intense rainfall events after dry periods could see the increased leaching of nutrients from soil. This will also depend on the land use across the PDNP with crop type, and application of fertiliser playing an important role. There could also be increased movement of other contaminants – such as heavy metals - from soil into water catchments. **[M]**

What is the adaptive capacity of healthy soil? ***[Overall adaptive capacity rating: MODERATE]***

There is potential for some soils to recover from damage without intervention. Severely damaged soils may need management interventions to enable them to become more resilient to climate changes. Examples include the planting of vegetation cover on eroding areas, a reduction in ploughing, a reduction in the use of large machinery, and reduced livestock density. In addition, reducing nutrient and pesticide input will help to improve soil health. **[M]**

The PDNP has a diverse geology, and wide varieties of soils types are present. This increases the adaptive capacity of the soil resource as a whole. **[VH**] However, there are many large expanses of homogenous land management types within areas of the PDNP. For example, the improved grassland landscape of the White Peak and the deforested grazed valleys of the Dark Peak mean that within these areas soil health faces similar pressures and will have a lower adaptive capacity as a result.

Agri-environment schemes are available which can help improve soil health, but the current trend is for a reduction in uptake in the PDNP. The future of such schemes is also very uncertain. However, water companies and other landowners are investing funds into restoration particularly in the uplands. **[H]** Some degree of resilience is aided by organisations such as Natural England and the SSSI designations covering some areas of the PDNP. Planning policy and the work of PDNPA partnerships also help to safeguard the existing resource. **[M]**

Information on best practice in soil management is widely available, and is subject to ongoing research. There has been shift in recent decades away from the perception of soil as an abiotic growing medium, towards recognising the importance of soil biota and viewing soils as habitats. This shift in perception may help to secure sensitive land management practices and therefore aid the adaptive capacity of soils. **[H]**

Key adaptation recommendations for healthy soil:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Increase woodland and scrub creation schemes in appropriate locations to reduce run-off and replenish soil organic matter.
- Strongly discourage the removal of native woodland or trees in planning cases, and increase mitigation needed when it does occur.
- Shift perception of the landscape away from being fixed to a more dynamic system. Accept that change should happen and habitat types need to be allowed to change in some areas for a net environmental gain, where it would benefit the special qualities of the PDNP.
- Significantly reduce artificial fertiliser and pesticide use in agriculture.
- Encourage farmers to reduce ploughing or change ploughing implements and use cover crops on any arable land.
- Create and maintain diverse hedgerows and buffer strips around fields.
- Create more flower-rich meadows.
- Continue reducing bare peat areas and revegetate other bare patches on blanket bogs.
- Pilot a ‘rewilding’ or ‘wilding’ trial scheme with no fixed conservation aims and monitor the impact on soil health.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

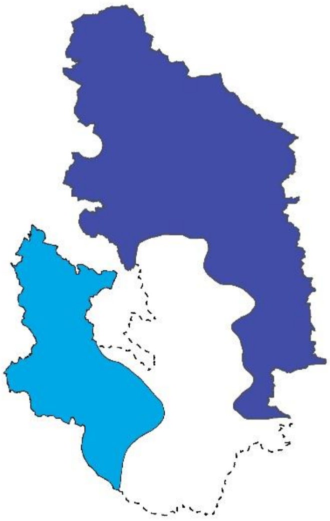
- Reduce livestock levels and trampling especially in areas vulnerable to erosion.

High open moorland and edges

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High

Features assessed:



- Open moorland, heath & edges
- Open uplands
- High open moorland plateau

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Undeveloped places of tranquillity and dark night skies within reach of millions
- Landscapes that tell a story of thousands of years of people, farming and industry
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

High, open moorland is an extensive and exposed landscape. It is found extensively in the Dark Peak and in some areas of the South West Peak, including Axe Edge and Goyt's Moss. The high and undulating topography is a result of the underlying Millstone Grit, allowing expansive views to distant skylines. The gritstone also results in occasional rocky outcrops or tors. A thick layer of blanket peat enhances the smooth, gently rolling nature of the landscape. The peat is incised, however, by eroded channels known as groughs that feed into rocky clough heads.

Ancient tree stumps found within the peat are evidence that trees have been a part of this landscape in the past. The current management regimes of sheep grazing and cutting or burning for grouse rearing maintain the openness of the landscape. However, in some areas scrub is present on the moorland, typically dominated by birch, willow and rowan.

Traces of human activity are also present on many of the moorland plateaus and edges. These include lithic scatters (flint and chert), extensive prehistoric settlement sites and field systems, ancient routeways, boundaries, mineral extraction and military training sites.

How vulnerable are high open moorland and edges?

High open moorland and edges in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a moderate adaptive capacity.

High open moorland and edges in the PDNP are in generally poor condition, with blanket bog in the worst state ecologically and hydrologically. They are particularly sensitive to hotter, drier summers and the resulting wildfire and erosion potential. Moorland edges also often have a high heritage significance, and surface and buried archaeological features are very sensitive to factors such as changes in vegetation, soil erosion and wildfire.

High open moorland and edges have a moderate adaptive capacity, but realising this is reliant on economic subsidy and management regime agreement in the long term, unless radical changes to the landscape are allowed to take place. The adaptive capacity of archaeological sites is lower once they have reached the point of being exposed through soil erosion or wildfire for example.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

There are extensive open uplands in the PDNP. Using a narrow definition of this feature group, there is an abundant resource of open areas for recreation, dramatic views and escape.

However, the condition of the habitats within these open areas is in some cases very poor. The blanket bog landscape of the PDNP is the most degraded in the UK. Extensive gullying means bogs are now much drier than when they were formed, meaning they are unable to function as bogs and form peat. The potential for blanket bog to be restored to an active state is limited by the extent of erosion and poor hydrological state. This also effects archaeological artefacts, earthworks and buried deposits especially at the plateau edges.

The peat of the PDNP is highly contaminated from historic industrial pollution, containing high levels of heavy metals. The high volume of recreational traffic in some areas can cause routes to erode, for example the so-called 'Bog of Doom' on the Cut Gate path.

Bracken dominates in some areas and Sitka spruce colonisation is a significant problem in the High Peak moors. Management of heather moorland by burning is still common despite an increasing body of evidence suggesting it can be harmful, particularly on deep peat. The pattern created by controlled burning has a strong visual impact on the landscape. Where areas have become dominated by one species such as heather or purple moor-grass, the aesthetic value of the uplands is also arguably reduced.

The high volume of visitor numbers during the busiest times of the year, particularly to key areas such as Kinder Scout or The Roaches can detract from the sense of remoteness and escape these open landscapes afford.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Sedimentation or erosion

Hotter, drier summers coupled with more extreme weather events may increase rates of erosion on damaged peatlands. Erosion could occur both during drought periods via wind and during winter storms via water. **[H]** Wetter winters in general could also lead to increased erosion of peat, which is already relatively thin in places. This erosion has the potential to cause root damage to heather and other species increasing sensitivity to winter desiccation, and to irreversibly damage archaeological sites. **[H]** This could change the look of the landscape and make revegetation more difficult.

Direct impacts of climate change

Extreme events, such as heavy precipitation and severe wind, may lead to greater erosion of soils. Waterlogged ground could lead to changes in plant productivity and below ground biomass (e.g. root dieback due to anoxic conditions) in areas where waterlogging is not desirable. These extreme events could cause altered plant community composition. **[H]**

Drier summers could also result in changes in plant species. Drought adapted species such as heather may colonise areas that have previously been too wet. Overall, this could cause areas of peat bog to transition to dry heather moorland. This would adversely affect palaeoenvironmental deposits. **[H]**

Wetter winters could result in increased nitrogen deposition resulting in habitat structure and composition changes. Heather may become increasingly sensitive to temperature, and *Sphagnum* is particularly sensitive to increased Nitrogen. **[M]**

Invasive or other species interactions

Warmer, wetter winters and drier summers may lead to increased damage from species such as heather beetle, as well as an expansion of bracken to higher altitudes. Studies have shown bracken to be very damaging to archaeological sites. **[H]** Wetter winters could result in increased nitrogen deposition, which in turn could result in heather becoming more sensitive to heather beetle outbreaks. Furthermore, bilberry is at risk of being lost due to its sensitivity to *Phytophthora*. **[M]**

Dry bogs can result in fractured, fragile surfaces. This may lead to more opportunities for invasive or non-native plant species to colonise, resulting in changes to habitat character and potentially increasing evapotranspiration - exacerbating the problem. **[L]**

Human behaviour change

Drier summers and wetter winters could change the levels of livestock grown in the uplands. An increase in the intensity of agriculture could have negative impacts character of the open uplands. Furthermore, spring burning of heather could become increasingly problematic. Although the landscape would likely stay open in character, it may be in an even poorer condition than it is already, negatively affecting its special qualities. **[H]**

Hotter summers may lead to increased tourist numbers. Visitor Hotspots, such as Kinder Scout, are typically sensitive to an increase in visitors. More visitors may lead to increases in litter and the chance of wildfire along, with a loss of peacefulness and a sense of wilderness. **[M]**

Increased atmospheric carbon dioxide levels may increase the demand for renewable energy installations. Such installations may be small scale (for individual settlements) or larger scale wind farms. The expansive, rolling nature of the landscape means any installations are likely to have a large detrimental visual impact, damaging the landscapes inspirational features. Further damage to the peatlands hydrology may also occur. However, the likelihood of this occurring may be low. **[L]**

An increased risk of flooding to downstream catchments may result in a demand for action by residents. Policy makers may decide to increase efforts currently underway to restore the hydrology of the uplands through, for example, revegetation of bare peat or woodland establishment around the edges of bogs. Such actions could reduce the impact of increased extreme events such as flooding, and would also diversify the appearance of the landscape. **[L]**

Other indirect climate change impacts

Hotter, drier springs and summers could result in water table level changes. Drier ground is more susceptible to wildfire, which can lead to vegetation damage and increased soil erosion and loss, including damage to archaeological sites. This risk of wildfire would be compounded by an increase in visitor numbers during hotter, drier periods. There may be a loss of public access to come areas at some times, either as a precaution, or in the aftermath of a fire. **[H]**

Nutrient changes or environmental contamination

Wetter winters followed by drier summers risks nutrient flushing and concentration in upland habitats. This could result in habitat composition changes, particularly in areas of wet heath of the species-rich flushes found on moorland edges. **[L]**

What is the adaptive capacity of high open moorland and edges? ***[Overall adaptive capacity rating: MODERATE]***

The large size of upland habitat patches in the PDNP, paired with some topographic heterogeneity will increase adaptive capacity to climate change. **[H]**

Overall, the uplands areas with more diversity in species and topography will be more resilient to change. However, areas dominated by a single species such as heather or purple moor-grass have less adaptive capacity. **[H]**

The relatively high growth rate of heather and moorland grasses increases their resilience; however, erosion lowers this capacity by reducing the seedbank. In contrast, the regenerative capacity of peat is extremely low due to its slow accumulation rate. **[M]**

Economic subsidies are currently in place for the maintenance and restoration of heathland, meaning the landscape will likely remain open in the short to medium term. However, the future of environmental land management schemes is very uncertain. **[H]** Furthermore, organisations (including Moors for the Future Partnership, South West Peak Partnership, National Trust and the Royal Society for the Protection of Birds) are currently working to restore upland habitats in the area. **[H]** Although many skills and techniques are already in place, there is very likely to be substantial disagreement between different stakeholders about the future of land use in the uplands. **[M]**

Key adaptation recommendations for high open moorland and edges:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Native trees and scrub should be encouraged around the plateau edges to increase resilience of upland habitats and protect blanket peat, but archaeological sensitivities need to be taken into account in the management of tree cover. More trees across the currently open upland landscape may assist with climate adaptation and mitigation, along with ecosystem service provision.
- Pilot a 'rewilding' or 'wilding' trial scheme with no fixed conservation aims and monitor the impact on this feature.
- Reduce fragmentation via restoring and improving corridors between moorland habitats to strengthen the ecological network.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Increase structural diversity of the landscape to improve resilience to change

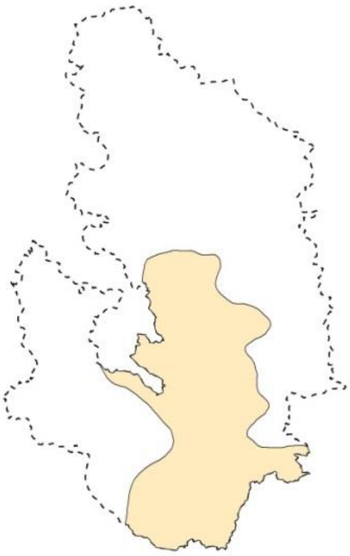
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the landscape in which the feature is found. By doing so the condition of the feature, and therefore its resilience to climate change impacts, should be enhanced.

- Encourage flexible land management to facilitate the development of a more diverse habitat composition and structure.
- Enable habitats to respond to climate change - do not view the landscape as fixed but allow room for change.

Limestone dales

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Features assessed:

- Limestone dales
- Limestone gorges and cliffs
- Karst valley systems of limestone dales and gorges created by historic river systems

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Undeveloped places of tranquillity and dark night skies within reach of millions
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

The Limestone Dales in the White Peak are steep sided valleys that cut through the limestone plateau, creating a distinctive landscape. This striking and often hidden landscape attracts visitors due to its natural beauty and tranquillity.

The area contains many outstanding karst features and has a high number of designated sites. There are 18 geological and 10 mixed interest Sites of Special Scientific Interest (SSSIs) and 97 Local Geological Sites.

The land is predominately used for farming but also incorporates flower-rich grasslands, ancient ash woodlands, rivers, caves and rocky outcrops.

The rivers that run through these limestone dales support a variety of species such as white-clawed crayfish, lamprey and dipper. Caves and woodland within the Limestone Dales support a large number of bat roosting sites and important woodland bird populations. Calaminarian grasslands associated with spoil heaps left over from the lead mining industry are also present. Many limestone faces that now provide important habitat are the remnants of former limestone quarrying (see Limestone Grassland).

How vulnerable are limestone dales?

Limestone dales in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity.

The condition of limestone dales in the PDNP is generally good but subject to some pressures. Changes to water levels could have a major impact on habitat and how the land is used in the future. This will affect the appearance and appeal of the landscape. Damage to parts of this feature will be irreversible, reducing its adaptive capacity, however there are schemes which could help with adaptation and a large proportion of the sites are formally protected.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The Limestone Dales of the White Peak have national and European importance. A large part of this area lies within the Peak District Dales Special Area of Conservation (SAC). There are also designated geological and mixed interest SSSIs and Local Geological Sites. They provide outstanding wildlife value through the different habitats they support.

Currently the majority of land is used for livestock farming. As some dale side grasslands have become uneconomic for grazing there is an increasing amount of scrub. This can affect the wildlife and distinctive flora of the grasslands, however scrub in itself provides an important transition between woodland and grassland. While this affects the appearance of the Dales it does not negatively impact its other valuable qualities.

The quality of water in the Limestone Dales is generally good with some exceptions. Some nutrient pollution and sedimentation is believed to be associated with changes in farming practices. These include a rise in intensity of livestock production, fields being treated with higher rates of nutrient application and larger numbers of cattle remaining indoors during the winter.

The Dales are very popular with visitors especially those who enjoy walking, cycling, rock climbing and caving. Certain locations can get particularly busy at peak times of the year meaning the sense of tranquillity can be reduced due to high visitor numbers. Some former limestone quarries, for example in Millers Dale, are now nature reserves in their own right. These provide an added element of natural and historic landscape interest with a particular relationship to the former railway routes that are now trails.

Some of the Dales have no roads and are wilder in character, contributing to their tranquil nature. 76% of the whole White Peak National Character Area is classed as 'undisturbed' and the steep sided valleys of the Limestone Dales are a significant tranquil feature.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Storm events leading to more intense rainfall and flooding could damage visitor access by impacting roads, bridges and other structures. An increase in run-off could also harm drainage systems leading to rights of way becoming unusable, more frequently disrupted outdoor events and restrictions put in place on access. This is likely to impact regular visitor numbers although there may be a short-term rise in visitors wanting to see what damage has been caused by these extreme events. **[H]**

Increased winter and reduced summer rainfall will result in changes of species present. This could impact visitors who come to see the landscape and wildlife in its current state. Limestone dales are sensitive to changes in water levels so drought could see the decline in species such as globeflower, mountain pansy and Jacob's ladder that are at the southern end of their range. A reduction in humidity may reduce numbers and diversity of invertebrates, therefore providing less food for birds including the pied and spotted flycatcher and lesser spotted woodpecker. Conversely increased winter rainfall could cause the water table to rise in some areas, bringing benefits for wetter habitats which may increase the appeal of these landscapes. **[M]**

A rise in summer temperatures in limestone dales is likely to lead to changes in the composition of woodlands, limestone grasslands, and limestone heath. This may poses a threat to the character and visual diversity of the landscape. **[M]**

Atmospheric pollution and the resultant acidification of water may cause chemistry changes and disruption of stalagmite formation in caves. Acidification of water could speed up the weathering effect on limestone and result in the loss or damage to limestone features. Both of these could alter the aesthetics of the landscape. **[M]**

Human behaviour change

Higher temperatures could lead to changes in farming practices as heat impacts on livestock welfare and farm viability. As a result there could be increased demand for new buildings and trees to provide shelter and shade. This is likely to be in wider dales that are already associated with agricultural buildings and subject to planning control. There might be an increased desire to remove drystone walls, affecting the historic landscape character. Tree establishment may especially be welcomed in areas where ash trees are currently being lost due to ash dieback. **[H]**

Agriculture soils are sensitive to drought. Drier conditions could prompt changes in cutting times of meadows and other agricultural activities with negative implications for food production, farm income, meadow flora, ground nesting birds and nectar-feeding insects. If there is insufficient water to sustain livestock it may result in a reduction in viable grazing areas. Drier conditions that result in droughts are likely to increase the demand for water abstraction from watercourses and groundwater aquifers, which could negatively impact properties, businesses and visitor facilities. **[H]**

The changes in temperature could see a rise in recreational pressure in locations close to water or with shaded areas. Increased visitor numbers could bring more congestion and traffic pollution, pressure on infrastructure, loss of tranquillity, a conflict between different user groups and disturbance for local residents and landowners. Increased footfall in certain areas could also increase erosion risk. Conversely, hotter drier summers could provide opportunities for a wider range of outdoor events. **[H]**

Increased demand for renewable energy, such as the addition of wind farms, has the potential to affect the landscape character and tranquillity. It could also change the emotional connection between residents, visitors and the landscape. However, it unlikely that wind farms would be installed in limestone dales due their operational requirements of open space to maximise wind. If any wind farms were built these would be likely to be on the higher plateaus and may be hidden from view in the dales. There is a higher likelihood of the installation of individual turbines in these areas however. In an assessment of landscape sensitivity to wind turbines by the PDNPA the Limestone Dales in the White Peak were judged to have moderate-high sensitivity to small turbines up to 15 metres. **[L]**

Sedimentation or erosion

More intense rainfall and flooding from storm events could increase landslides and erosion, leading to habitat loss and changes to the appearance of the landscape. Ash dieback will mean there are more standing dead trees which will be more susceptible to being swept away in extreme rainfall events. Storms are likely to cause damage to healthy trees as well. In places like Dovedale this could lead to the river becoming blocked, causing flooding upstream. **[M]**

The karst valley system of limestone dales and gorges are sensitive to any overall increase in rainfall. This could result in erosion of limestone features, changing the landscape aesthetics as well as an increase in run off and sedimentation in waterways. Archaeology, historic structures, habitats and species could all be lost or damaged due to this erosion. **[M]**

Invasive or other species interactions

Limestone dale woodlands are dominated by ash. Ash dieback disease is a major threat with between 60 and 90% of ash trees expected to be affected in the PDNP, with significant impact on the White Peak plateau and dales. Milder winters with fewer frosts could see an increase in the prevalence of diseases such as ash dieback which will alter the biodiversity and aesthetics of the landscape. Changes in temperature and rainfall can also put trees under stress, making them more susceptible to disease. **[H]**

Nutrient changes or environmental contamination

Groundwater in limestone dales is vulnerable to pollution. This is due to the many fissures and underground passages in the limestone linking it to the surface water. Increased rainfall could mean nutrient applications on farmland are more likely to be carried into groundwater if applied before heavy rainfall periods. When rivers are low during the summer pollutants can become particularly concentrated. This could then have an impact on water quality for residents and visitors. **[M]**

What is the adaptive capacity of limestone dales? ***[Overall adaptive capacity rating: MODERATE]***

Limestone dales have a complex hydrogeology and eroded features cannot recover their structure, therefore adaptation measures will not always be possible. Water management is especially difficult, which means the landscape may change in the future. Ash trees remain a high risk but most vegetation can recover or regenerate with some help. **[H]**

Agri-environment schemes and woodland grant schemes are in use within the Limestone Dales and can help to provide funding for adaptation measures. There may be White Peak partnership schemes available in the future, which will increase the funding opportunities for a fixed period. **[M]**

The majority of the Dales, 2,337 hectares, are included in the Peak District Dales SAC, and are SSSIs of both natural and geological importance. Most of the Dales are covered by the Section 3 legislation called the Natural Zone in the National Park Management Plan (NPMP), which means there is a presumption against any development. A variety of management options are available, however caution needs to be taken where there will be a negative impact on landscape character. Designation should support positive adaptation measures for the Dales and Section 3 legislation should protect them against damaging adaptation or mitigation. **[M]**

Key adaptation recommendations for limestone dales:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Protect geological features and maintain their visibility by removing or managing vegetation.
- Improve water use efficiency and rainwater harvesting, especially in remote locations which are dependent on springs and susceptible to drought.
- Provide advice, information and support to farmers on increasing organic matter in soils and other measures to increase carbon storage and improve drought tolerance of farmland.
- Maintain historic environment records to enable historic environment advice to be integrated with other land management advice, to help conserve historic environment assets.
- Encourage sympathetic management, restoration and creation of riparian habitats, particularly grassland, woodland and wetland, to stabilise river banks and reduce erosion and diffuse pollution.
- Install settlement ponds and silt traps to intercept run-off and sediment before it reaches watercourses.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.
- Undertake stream revetment schemes to slow flow, reducing rock face undercutting, stream bank erosion and minimise downstream flooding.
- More research is required to better understand the hydrology and role of artificial drainage on low flow river systems.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Monitor the spread of tree diseases, in particular ash dieback, and ensure appropriate mitigation measures. However, deadwood is a very valuable habitat and should be left standing unless it is a public safety hazard.
- Manage visitor access to popular locations to minimise traffic, disturbance, footpath erosion and other negative environmental impacts.

Adaptations that could aid other features

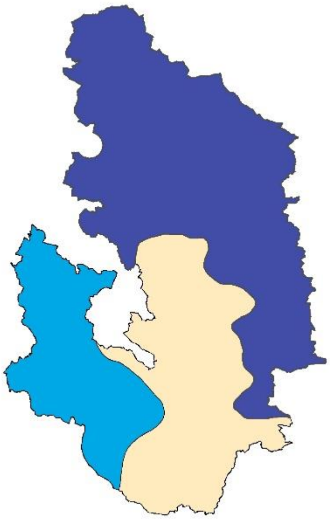
These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- In areas where it does not have a negative impact on the landscape character, establish trees to provide shade for wildlife, livestock and people and to regulate the temperature of watercourses.

Palaeoenvironmental remains and sequences

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature assessed:

- Palaeoenvironmental remains and sequences

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

The soils, sediments, and peats in the PDNP are a very important source of palaeoenvironmental information.

They help provide an insight into how the climate has changed, along with past vegetation, habitats and human activity, and long-term environmental changes.

In good condition, the waterlogged peatlands of the Dark and South West Peak in particular should provide a good level of protection for palaeoenvironmental evidence buried beneath the surface. These environments are scarce in England, hence their value as a source of preserved organic remains. In addition, organic remains can also be found in the White Peak where pollen for example has been found in tufa - a porous limestone sediment.

Valuable palaeoenvironmental evidence can also be contained within any buried soils and archaeological deposits (see 'Buried soils, archaeological remains and deposits'). Sediments within caves and cave systems are also a very valuable, yet fragile, source of palaeoenvironmental information.

How vulnerable are palaeoenvironmental remains and sequences?

Palaeoenvironmental remains and sequences in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, and a variable current condition and a moderate adaptive capacity.

The current condition of these features is largely unknown due to their hidden nature, but certain areas such as the peat bogs of the Dark and South West Peak are known to be at risk. Climate change effects that expose deposits or alter soil conditions are likely to be damaging. As these features are buried any change in the surface conditions from extreme weather events will have a key potential impact. Sediments in underground sites, fissures and caves are equally important and must not be overlooked. These may be particularly vulnerable to environmental change.

There is very limited capacity for adaptation as once they are damaged the information that they contain cannot be recovered. However there are adaptations that can be made to help preserve the existing resource. These features are particularly significant where they can be related to other heritage features such as prehistoric settlement and field systems or human activity within caves, for example.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The current condition of palaeoenvironmental remains and sequences in the PDNP is difficult to ascertain and is likely to be variable. The survival of organic remains and deposits is dependent on the environment into which they were originally buried, as well as subsequent conditions. It has been found that certain materials are better preserved in acidic, and some in alkaline, environments.

In the Dark and South West Peak for example, peat bogs are a very important due to their value in preserving buried organic material. This is because numerous materials survive better in anoxic environments (i.e. those without oxygen) and the waterlogged nature of these bogs mean that the majority of soil microorganisms along with fungi are not able to operate as decomposers.

Unfortunately, PDNP peat bogs are generally in an extremely poor condition with a low or erratic water table (see assessment of 'Blanket Bog') which means it is likely that some items have already been lost or degraded. Previous human drainage of bogs and other soils across the PDNP will have already degraded or destroyed buried soils and some archaeological deposits. In addition, ploughing, development and other farming practices are very likely to have affected the condition of these features.

Tufa has also historically been exploited in the PDNP as a source of lime for agriculture and as a construction material, but evidence for this is limited to a small number of quarry sites.

Sediments in underground sites, caves and fissures are also a significant source of potential palaeoenvironmental information. Relatively few investigations have been carried out on these deposits.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Drier summers and wetter winters could have a significant impact on palaeoenvironmental remains and sequences including those within caves, fissures and underground deposits. Drier summers could also have a significant impact on sites with good organic preservation. Drying of soils may increase the cracking of the surface allowing oxygen to enter the subsurface region and increase microbial action activity and oxidation of materials. In addition, the cycle of wetter winters and drier summers will cause further damage to waterlogged archaeological deposits. In PDNP peat soils in particular these changes could see the destruction of organic remains. **[H]**. Information may be lost where valuable palaeoenvironmental and organic remains are vulnerable to changes in groundwater levels. **[H]**

Increased surface water run-off in extreme storm events could see peatlands damaged and hydrology impaired as gullies are formed and widened, putting organic remains put at risk. River valleys at risk of flooding could also experience a significant impact on remains. There may be changes to the water table or degradation of riparian habitats. **[H]**

Increased annual temperatures could also accelerate microbiological activity that could lead to the destruction or degradation of organic remains that are sensitive to such change. **[M]**

Human behaviour change

Drier summers could lead to changes in the economics of upland farming. For example, drier heathlands become more suitable for intensive management and grazing regimes may be changed. Erosion may be increased by overgrazing and high stocking levels, damaging remains and deposits. Agricultural improvement may lead to changes in soil chemistry - such as changes in pH. This could affect preservation of materials. **[H]**

Temperature changes leading to longer growing seasons could see new types of crop and marginal areas becoming more viable. Pasture converted to arable crops and associated ploughing and drainage may disturb soil layers while physical buried remains could be damaged. **[M]**

Increased pressure for construction of renewable energy installations such as wind turbines, particularly on exposed areas, could affect the feature, as soils will be sensitive to installation of equipment, compaction and disturbance. This may cause an increase in erosion and change the hydrology or an area leading to drying of site. However, current planning policies make renewable energy installations such as wind turbines on moorlands less likely. **[M]**

Periods of extreme drought could lead to demand for more water to be taken from the ground or rivers. Resulting changes to the water table could negatively affect riparian habitats and see biological remains damaged if land dries out. **[L]**

Nutrient changes or environmental contamination

Atmospheric changes, for example increased carbon dioxide levels that result in the chemical composition of water being altered could have an impact on the anoxic environment found in soils and sediments. It has been shown that micro-organisms are very sensitive to even small changes in water chemistry and are also important for maintaining an anoxic environment. If this environment is not maintained some remains may be lost or damaged. **[H]**

Sedimentation or erosion

Degraded bogs in particular are sensitive to erosion, so an increase in summer droughts and winter storms could result in bare peat damaged by water and wind. This also applies to other soils across the PDNP including cave and fissure deposits. However, the deposition of eroded sediment could protect other sites. For example, while some remains could be exposed by increased erosion, some could also be buried further by the silt and material that has been moved. The uncovering of new sites and materials through increased erosion should only be considered a positive result of climate change if there is resource to record the new information - exposure also is likely to see the new sites damaged or lost. If erosion rates increase, remains and deposits may also be exposed to oxygen as water table falls. **[H]**

Other indirect climate change impacts

Drought and drier ground conditions could lead to an increased incidence of wildfire in the PDNP, particularly on degraded bog and heath sites. Potentially large areas of peat and vegetation could be lost further increasing erosion and peat loss. In such conditions dry peat also becomes more susceptible to damage from managed burns and there is more potential for them to get out of control. Fire can damage remains within or below the peat and mean they are lost or severely affected. **[H]**

Invasive or other species interactions

If warmer winters lead to higher populations of burrowing mammals such as badgers, moles and rabbits buried archaeological deposits could be disturbed and hydrology of the area in question could be changed, with drier sites leading to less preservation of organic materials. **[M]**

The fragile surface of damaged bogs is sensitive to increased erosion if winter storm events increase in frequency and intensity. In other habitats the areas where trees are uprooted and remains are therefore exposed or damaged could increase. Erosion may lead to more opportunities for invasive species to colonise, potentially drying soils further and increasing the risk of damage to remains and deposits. **[L]**

Buried deposits could be sensitive to more rapid scrub and tree colonisation as a result of increases in atmospheric carbon dioxide and nitrogen levels and increased average annual temperatures. Not only can they be disturbed directly by root systems, but also an increase in evapotranspiration could lead to drying of some sites. **[L]**

What is the adaptive capacity of palaeoenvironmental remains and sequences? ***[Overall adaptive capacity rating: MODERATE]***

Although the features can be found across the PDNP in a wide diversity of locations, some of the most important places are probably the waterlogged peatlands - but there are few where the upper layers are waterlogged. Important pollen records may be retained in non-waterlogged soils. Because these are hidden features, it is unknown exactly where important remains can be found lowering the capacity for human adaptive measures to be implemented. **[M]**

Some money from grants and partners is available for peatland restoration activities, but there is currently a decrease in the uptake of agri-environment schemes in the PDNP. The future of environmental land management schemes after the UK has left the European Union is also very uncertain. Archaeological deposits, apart from those in peat, are at risk because they often do not have sources of funding available to secure the habitat in which they are situated. Those areas that do not come under planning control and do not have funding sources available to secure them outside of environmental land management schemes will be some of the least adaptable. **[H]**

Several organisations carry out or oversee peatland and other habitat restoration projects in the area, in order to help safeguard these features. They include Moors for the Future Partnership, National Trust, Royal Society for the Protection of Birds and South West Peak Partnership. These increase the capacity for adaptive measures such as habitat restoration to be taken. However, only a small proportion of the park is in public ownership and the involvement of private landowners taking advantage of current land enhancement opportunities will be mixed in uptake and extent**. [H]**

There is a lack of clear information about what and where remains and sequences are. Most of these features will be at unknown sites that do not even have a status as a 'non-designated heritage asset'.

Some management to protect features could be taken, however it is unlikely that there will be a co-ordinated approach on the landscape scale. Information and expertise is however available from the organisations highlighted above and others including Historic England and PDNPA Planning and Cultural Heritage teams. **[L]**

Key adaptation recommendations for palaeoenvironmental remains and sequences:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Habitat enhancement to stabilise the water table, which will create stable environmental conditions for preserving remains and deposits.
- Integrate heritage protection into moorland restoration schemes.
- Create research partnerships, for example with universities, to provide a better understanding of these deposits across the PDNP, to include scientific dating.
- Phase out burning on blanket bog. Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Investigate funding for strategic survey to locate and catalogue sites of archaeological interest and potential (deposit modelling).
- Improve the knowledge of cultural heritage features to help target conservation efforts.

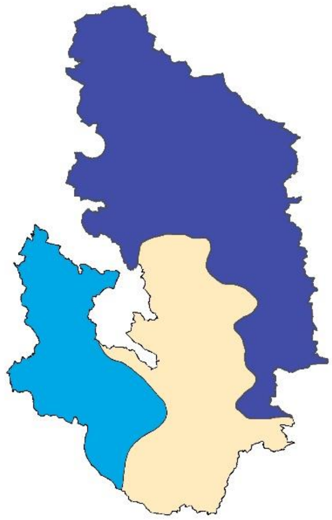
River valleys

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Features assessed:

- River valleys
- Broad, meandering river valleys & riverside meadows
- Reservoir valleys with woodland
- Pastoral river valleys



Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- An inspiring space for escape, adventure, discovery and quiet reflection
- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

River valleys are one of the iconic landscape types of the PDNP and they differ depending on the area in which they occur.

In the uplands of the Dark and South West Peak the rivers run through steeply sided valleys while further downstream the valleys open out and include wider floodplains. The valleys within the White Peak are around a combination of permanent rivers and streams and in several locations they have associated tributaries that run dry for periods of the year. For an assessment of these rivers as habitats, see 'Rivers and streams' and 'Vanishing rivers'. In the Derbyshire Peak Fringe, the river valleys are broader with wider floodplains and support marshland habitats and wet grasslands.

The main valleys of the White Peak are the Manifold, Wye and Dove. In the South West Peak, the Hamps and Dane flow, while the Derwent forms the main valley of the Dark Peak. Several other smaller rivers join these larger flows of water. In the Dark Peak there are deep flooded valleys containing reservoirs such as Howden, Derwent and Ladybower (see 'Reservoirs').

The majority of PDNP riverside land is pasture for sheep or cattle. There are also some areas of native and plantation woodlands (see 'Estate lands and designed landscapes', 'Woodlands' and 'Wet Woodlands').

How vulnerable are river valleys?

River valleys in the PDNP have been rated ‘moderate’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition, but with a high adaptive capacity.

River valleys in the PDNP are generally in functional condition, though as active hydrological systems changes are fast. An increase in rainfall intensity and flooding is the key potential impact of climate change in river valleys. However, natural flood management schemes are part of the Department for Environment, Food and Rural Affairs (DEFRA)’s 25-year plan, and there are multiple management strategies that could be implemented to increase significantly the adaptive capacity of river valleys.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

The condition of river valleys in the PDNP is variable and can change very quickly. For example, intense rainfall in November 2019 on already saturated ground saw widespread flooding particularly on low-lying areas resulting in a fatality as well as damage to farmland, roads and properties.

Not only does such flooding affect the land and the varied habitats and historic environment found in river valleys, it can also affect water quality. Many PDNP access routes such as roads, railways tracks and even walking routes pass through valley bottoms and they too can be damaged. Valley bottom farmsteads and other buildings are also at risk from damage.

Many issues currently affect PDNP river valleys. Several non-native invasive species associated with water are present. These include mink, signal crayfish, Himalayan balsam and Japanese knotweed. In addition, plantations of non-native conifers are present. These are likely to be affecting water quality, river valley landscapes and water ecosystems. Signs of ash dieback have been found in native woodlands.

Although erosion and sedimentation in river valleys are natural processes, they have been impacted by upstream erosion of peat - in particular contributing to problems of water acidity and siltation of waterbodies like reservoirs within the valleys.

Water quality and river valley habitats have been affected negatively by intensification of agriculture and high levels of livestock, contamination from industry and sewage discharge.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

River valleys are very sensitive to climate change especially if there is an increase in the intensity and frequency of storm events. Sudden flash storms can cause considerable damage and even loss of life, as occurred in 1989 when the River Dane flooded at Wildboarclough and again in 2019 when the Derwent flooded at Darley Dale. Repeated flooding can alter or damage archaeological and historic features and can have a significant impact on the riparian habitat by damaging nests and burrows, as well as habitats for species such as the water vole and kingfisher.

Fish populations can also be harmed because fish eggs could be washed away with river gravel or be damaged by silt. This would in turn affect recreational fishing in the valleys. **[H]** River valleys are sensitive to changes in rainfall and are vulnerable to flooding which could then affect farming, settlements, and visitor infrastructure. **[H]**

In contrast, hotter drier conditions and low rainfall during summers could that streams and rivers are dry for longer periods of the year. This could then impact aquatic habitats and species by changing the quality of water, river levels and the water flow. This in turn has the potential to impact farming and local water supply in the valleys. **[M]**

Sedimentation or erosion

Changes in rainfall patterns may result in an increase in erosion processes in river valleys. Rivers may become increasingly silted in places due to an increase in catchment-level soil loss. Rivers are highly vulnerable to topographic changes. Rivers may be realigned with changes in river pathways also seeing deeper channelling, meanders being cut-off, and new oxbow lakes formed while riverside farmland may flood more frequently. Archaeological features, especially those associated with former water management and bridges could also be lost or damaged. **[H]** Storm events may affect riverbanks and depositional features, together with riparian habitats used by species such the water vole. It may be that marginal and aquatic vegetation such as water crowfoot beds are washed away. **[H]**

Human behaviour change

Hotter summers could result in the growth in visitor numbers to popular tourist hotspots such as Dovedale. Such a rise would increase fire risk, litter being left and may case the loss of the peaceful quality of the setting. Rising visitor number may also cause significant erosion through footfall and parking. Conversely in some locations numbers may fall, driven by degradation of the natural beauty of the area caused by factors such as tree disease outbreaks, dry rivers and the loss of habitats. **[M]**

Drier summers would be likely to increase demand for water abstraction, while wetter winters may result in installation of new flood defences, dredging and even modification to the river channels to combat an increased risk of flooding.

River ecosystem and habitats are sensitive alteration of river channels. Species associated with rivers may decrease if river levels and channels are modified. River valley processes will be sensitive to changes in farming practice occurring due to climate change. The aesthetics of PDNP river valleys are likely to change, including the historic landscape character. **[M]**

Increased demand for renewable energy may result in river flow being harnessed for energy generation. The addition or modification of reservoirs and installation of hydropower schemes (including small-scale and microgeneration) would affect the landscape, habitats and aesthetics. **[L]**

Invasive or other species interactions

Fewer frost events during warmer winters may lead to an increased prevalence of diseases that affect woodlands, such as ash dieback. This could alter biodiversity and aesthetics of the valley landscape, and have a significant impact on the rate water reaches the river channel. **[M]** Changes in growing conditions caused by drier summers and wetter winters may lead to an increase in the number and prevalence of invasive and nuisance species. Water and waterside habitats are particularly vulnerable to invasion and dry, waterlogged or damaged soils are more susceptible. This could see changes in biodiversity and the appearance of river valleys. Historic structures could also be affected by invasive species. **[M]**

Nutrient changes or environmental contamination

Increased winter rainfall, run-off and and flooding events could increase the level of nutrients input to riverside meadows, pastures and woodlands. Where pollutants are present at the head of a valley this would also increase potential for contamination to occur over a wide area. This could affect habitats - changing the composition of species present and alter the human use of the landscape. **[M]**

Water quality is sensitive to changes from atmospheric pollution, which could also change water chemistry. Acidification of water could occur as atmospheric carbon dioxide increases, and rivers could be less resilient to eutrophication. As a result, landscape scale changes could occur – to biodiversity, land-use and aesthetics. **[L]**

What is the adaptive capacity of river valleys? ***[Overall adaptive capacity rating: HIGH]***

Rivers will respond to changing water regimes by adapting their channel form, flow and shape. However, damage to access, farmland and settlements during extreme events will requires long recovery periods. River valley ecosystems will have higher adaptive capacity where natural processes are allowed to take place. **[M]**

There is a diverse range of river valleys throughout the PDNP with a mixture of natural river systems and altered ones, flowing through a range of different bedrock and soil types. Valleys with a higher diversity of habitats and species will have a higher adaptive capacity than those with more homogenous characteristics such as improved grassland, conifer plantations, of even the ash dominated woodlands of the White Peak. **[M]**

Flood Management and Prevention Schemes in DEFRA's 25-year plan for Natural Flood Management include tree establishment, riverbank restoration, building small-scale woody dams, reconnecting rivers with their flood plains and storing water temporarily on open land and Flood Defences. A move towards these type of interventions would increase the resistance and resilience of PDNP valley landscapes. Agri-environment schemes and Woodland Grant schemes are also in currently use. Such interventions can sometimes adversely affect historic features and character. **[H]**

Work to increase the resilience of rivers and river valleys is already being carried out by organisations such as National Trust, Moors for the Future Partnership, South West Peak Partnership Staffordshire and Derbyshire Wildlife Trusts and Trent Rivers Trust. Catchment partnerships are a major potential future resource for work to be undertaken. **[H]**

A variety of management options is available to manage watercourses, to manage farmland, and to promote structural and species diversity within river valleys. **[M]**

Key adaptation recommendations for river valleys:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Accept that landscape character and habitat types cannot remain static in PDNP river valleys, and that management changes will need to happen to enable resilience to climate change.
- Improve the management of riverside grasslands, and create more wet meadows. They can be used to temporarily store floodwater and reduce the effects of large rainfall events.
- Remove manmade impoundments where appropriate, especially those in small watercourses to help increase habitat quality, decrease downstream flooding and landscape aesthetics.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Regular monitoring of key sensitive heritage features (such a listed bridges).
- More research is required to better understand the hydrology and role of artificial drainage on low flow river systems.

Improve current condition to increase resilience: Increase structural diversity of the landscape to improve resilience to change

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the landscape in which the feature is found. By doing so the condition of the feature, and therefore its resilience to climate change impacts, should be enhanced.

- Management of river valleys should allow space for natural processes to occur. Allow rivers to meander, and exclude livestock to allow space for riverside woodland and scrub to develop in appropriate locations. This should help to control nutrient input and may reduce water temperature increases.
- Manage the whole catchment including the upper slopes to reduce run-off and increase lag-times. Create more clough woodland to reduce flood risk and erosion of valley sides.

Accept changes to feature

These recommendations are about adapting ways of thinking to be accepting of inevitable change. While some changes may be negative, this also presents a chance to seek out any positive opportunities that may be caused by climate change.

- The potential for new reservoirs should be raised as an issue in the review of the Local Plan for the PDNP where this supports climate change adaptation, nature recovery and effective visitor management.

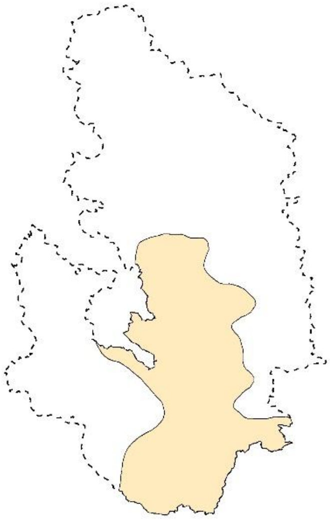
Show caves and caverns

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:

- Show caves and caverns



Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

Within the PDNP, there are four show caverns. Treak Cliff, Blue John, Speedwell and Peak caverns are all situated around Castleton in the White Peak. There are further examples just outside the boundary of the PDNP - Poole's Cavern in Buxton and the Masson and Rutland Caves at the Heights of Abraham in Matlock Bath.

Although there are other caves in the PDNP, the focus of this assessment is the show caverns and the potential impacts of climate change on their condition and sustainability as visitor attractions. In Castleton, the cave systems run much further than where the public are taken on tours, and are only accessed by cavers.

Peak Cavern has a large cave entrance but is part of a much larger cave system. In recent years, it has expanded its offer and is now an evening venue for concerts and film screenings.

Speedwell Cavern was once a lead mine and opens out into a network of natural caves and rivers. The tour for the public is by boat.

Blue John and Treak Cliff Cavern are both accessed on foot and feature locations where Blue John was, and still is, excavated. This unique mineral, of which there are 15 distinct veins, is used in jewellery.

The show caves and caverns provide evidence for former methods of industrial working which forms an important part of their tourism interest.

Most of the land in the Castleton catchment is, like the show caverns, under private ownership. The National Trust does own some of the land at Winnats Pass and Windy Knoll. Peak Cavern is part of the Duchy of Lancaster and is tenanted.

How vulnerable are show caves and caverns?

Show caves and caverns in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to moderate sensitivity and exposure to climate change variables, a relatively stable current condition, and a moderate adaptive capacity.

An increase in flooding of the caverns is one of the key potential impacts of climate change. This could mean they close for longer and more regularly resulting in the attractions possibly becoming more seasonal. Changes in water levels and associated erosion could potentially damage historic features within the caves and caverns.

All four show caverns are in private ownership and appear to be reasonably sustainable businesses however it is not known what financial resources they have to invest in adaptations, and the range of changes that could be made is relatively limited. The feasibility of investing in natural flood management techniques in the catchment that feeds the caverns should be investigated.

Overall potential impact rating: MODERATE

Overall adaptive capacity rating: MODERATE

Current condition:

Castleton is a 'honey pot' village and is a very popular location within the White Peak for visitors and cavers. The four show caverns are open almost all year round – unless they are flooded.

Speedwell and Peak are active stream caverns and are connected. The water from both converges and forms the main underground drainage for the catchment area. Both were impacted by several periods of heavy rain in 2019. Speedwell was closed due to flooding for at least ten days, six of which were during the school holidays. Peak Cavern was closed for at least one day, but on several other dates only short tours of the entrance chamber could be offered as the inner part of the cavern was flooded.

Castleton caves have some of the highest known levels of radon gas in any cave system, and this has to be monitored on an ongoing basis.

Several of the caverns are units of the Castleton Site of Special Scientific Interest (SSSI). A partnership has been set up by Natural England and local cavers to monitor the condition of the SSSI, which has shown them to be in a favourable and stable condition in recent years.

What are the potential impacts of climate change? ***[Overall potential impact rating: MODERATE]***

Direct impacts of climate change

Caves are sensitive to flash flooding and also drying out in summer droughts - particularly Speedwell Cavern where access is by boat so the water level can be too low or too high. Caverns could be closed to the public for an increased number of days, affecting profitability and position as a visitor attraction. These extreme conditions could also affect the historic features in the caves. **[M]**

Dry ground after drought periods may lead to periods of rapid run-off during intense summer storms. An increase in flooding of caves from such storms has the potential to be a risk to public safety, and thus to impact business sustainability. There could also be an increase in levels of carbon dioxide in caves during dry and still weather. **[M]**

The rate of erosion of limestone features could rise if continued increases in atmospheric carbon dioxide mean water becomes more acidic. This could affect processes sensitive to alterations in water chemistry such as stalactite formation. While this is unlikely to have a significant impact in the short term, it may affect the caverns as a scientific resource. **[M]**

Temperature changes could affect the levels of radon as its concentration depends on the temperature relative to the average temperature in the cavern interior. Increased concentrations are found during warmer weather so there may be a need for increased monitoring and ventilation of caverns. It is however unlikely to have a significant overall impact. Each system is unique in terms of ventilation and layout so it would be difficult to predict the response of each cavern. **[L]**

Human behaviour change

If the supply of visitors is disrupted by flooding events affecting access on the PDNP transport network, cavern businesses could suffer financially. Less reliable visitor numbers could affect profitability and their long-term future as a tourist attraction. The construction of new flood defences or re-routing of water could have varied impacts on the caverns. The hydrological network is very complex and the consequences of measures to prevent flood are unknown. **[L]**

Visitor businesses rely on maintaining footfall. If fewer tourists visit the area in wetter winters, cavern businesses may become more seasonal, creating a need to adapt and diversify. **[L]** Conversely hotter, drier summers could increase visitor number as people seek cooler places. Increased footfall at show caves could secure their future as a tourist attraction if the infrastructure is able to cope with rising numbers. Hotter drier summers could also affect the cave catchments. If pastoral farming is no longer sustainable, they may evolve into a more wooded landscape. This could reduce the speed of run-off, reduce flooding in the caves, and improve water quality entering system. **[L]**

Invasive or other species interactions

Increased atmospheric carbon dioxide and nitrogen coupled with increased annual average temperatures may lead to more rapid growth and longer growing season for vegetation around visitor facilities. Vegetation around cavern entrances may require management to occur regularly. **[L]**

Nutrient changes or environmental contamination

The condition of water in cavern systems is closely tied with that of water at the surface. In limestone landscapes, the many cracks and tunnels mean that cave water is sensitive to sources of pollution at the surface. Fertilizer applied for agriculture, coupled with milder weather could see warmer, nutrient-rich water entering cave systems and potentially creating better conditions for pathogens to reproduce. The overall impact though is likely to be relatively small. **[H]**

In addition, larger volumes of water flowing into the caverns after storm events could carry in an increased amount of organic material. Rotting material can cause a rise in underground carbon dioxide concentration. This can compound the effect of high numbers of people on carbon dioxide. However, carbon dioxide levels can easily be monitored, and this process is unlikely to have a significant impact on this feature. **[L]**

Sedimentation or erosion

Access to parts of the cavern systems could become more restricted by sedimentation if storms become more frequent and severe. Historic features could also become buried or damaged. Access for recording and survey could also be reduced. **[L]**

Wetter winters could see greater movement of sediment into caves and some tunnels sealed due to the high volume of water. This may encourage radon build up in places and increase the need for monitoring and ventilation. Conversely increased water flow could increase ventilation and reduce radon levels in places. This is however unlikely to have a significant overall impact. Each cavern will have a unique response depending on its layout, ventilation and other factors so impact is difficult to predict. **[L]**

Other indirect climate change impacts

An increased risk of wildfires during hotter, drier summers could reduce visitor footfall in the PDNP due to access issues. There is also potential for increased soil erosion after fires leading to increased sedimentation in caverns - although this is unlikely to have significant impact. **[L]**

What is the adaptive capacity of show caves and caverns? *[Overall adaptive capacity rating: MODERATE]*

Physical recovery from extreme events should be possible unless tunnels are blocked by large amounts of debris. However, financial recovery from repeated closure or reduction in business could be more difficult. It is unlikely that new show caverns in other locations could be opened. This is due to a lack of suitable large sites and planning constraints on new infrastructure. Impacts of climate change would also likely to be similar elsewhere, and new sites would need to be near a tourist centre. **[H]**

Although there is diversity in ownership and structure within the four existing show caverns and the drainage of water into and out of each, they are located within a very small area and therefore will likely be exposed to similar changes. They share many similarities and constraints in terms of access and the infrastructure of Castleton. This decreases the adaptive capacity of the resource. **[H]**

The PDNP show caverns are in varied private ownership. Three are run through limited companies incorporated at various times - Speedwell Cavern in 1973 and Peak Cavern in 1997, which are run by the same company directors, and Treak Cliff Cavern in 1998. Currently they all appear to be reasonably sustainable businesses but individual ability to invest in adaptation is unknown and likely to be mixed. Speedwell currently appears to have the largest assets, but the reliance on boat transport may mean it has a more limited scope for adaptation. **[M]**

Peak Cavern and Speedwell Cavern are within the Castleton SSSI, and condition monitoring is carried out in conjunction with cavers. While SSSI monitoring increases the likelihood to identifying problems and enabling them to be addressed, the designation could potentially make adaptation measures less likely to occur. If adaptations are deemed detrimental to the cave system, or if the administrative burden of interacting with public bodies such as Natural England deters future cavern owners, they may be less likely to be put in place. **[L]**

Management options for adaptation are quite limited. Although improving cave ventilation, air monitoring systems and upgrading infrastructure are possible; options for the management of watercourses to reduce flooding incidence and severity are much more limited. **[M]**

Key adaptation recommendations for show caves and caverns:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Ensure cave management plans consider need for increased ventilation, and continue to monitor levels of radon and other gasses such carbon dioxide into the future.
- Ensure planning policies are flexible and open to sympathetic adaptations for caves that do not harm historic significance.

Improve current condition to increase resilience: Increase structural diversity of the landscape to improve resilience to change

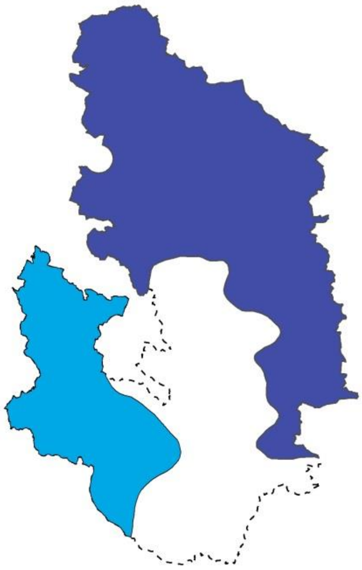
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the landscape in which the feature is found. By doing so the condition of the feature, and therefore its resilience to climate change impacts, should be enhanced

- Encourage natural flood management techniques within the catchments feeding the caverns – for example allow some pasture to revert to scrub or woodland in suitable places.
- Reduce farming inputs such as fertilizers, or paper pulp into system, to improve water quality and reduce toxin build-up in caves. Livestock levels should be lowered around streams and rivers as slurry is the main contributor to nutrients in rivers. Give consideration to good management of waste to improve catchment quality, including effective slurry store management. Low nutrient feed should be encouraged. Fertiliser and pesticide inputs should also be reduced to prevent spread into the watercourse.

Slopes and valleys with woodland

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature(s) assessed:

- Slopes and valleys with woodland
- Wooded narrow steep sided cloughs
- Meandering pastoral river valleys defined by woodland

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology

Feature description:

Areas of woodland on slopes or within valleys and cloughs can be found throughout the PDNP from small pockets to large tracts of wooded land.

In the South West Peak there are significant woodlands, particularly above Macclesfield and the Goyt Valley. Within the Dark Peak there are a number of woodlands including large areas of conifer plantation in the Derwent Valley. Around the moorland slopes and cloughs any woodland is smaller and more scattered in nature. For slopes and valleys with woodland in the White Peak please see the Limestone Dales feature.

Slopes and valleys with woodland provide a contrast to more open landscape types in the PDNP, such as heather moorland or pastoral farmland.

How vulnerable are slopes and valleys with woodland?

Slopes and valleys with woodland in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable condition and a moderate adaptive capacity.

Wooded slopes and valleys in the PDNP are already in a poor state, with low diversity and invasive species in many areas, and replacement by conifer plantations affecting others. An increased prevalence in extreme events, rainfall and higher temperatures would have a large negative impact on the woodland significantly affecting the feature. The feature may be damaged directly or indirectly by invasive species, nutrient changes and human behaviour change resulting from climate change.

Slopes and valleys with woodland are somewhat resilient as there are funds available through environmental stewardship options and other national schemes for maintenance, restoration and tree establishment. However significant intervention will be required in order to make this feature resilient to climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

In certain areas woodland diversity has been reduced by the isolation of their location, high levels of grazing by deer and sheep, and invasion by rhododendron. Deer and sheep alter the structure of the woodland, reducing woodland regeneration by damaging young trees and impacting plants on the woodland floor.

Diverse semi-natural habitats, such as native woodland, have been replaced in places by less diverse conifer plantations. Some native woodland habitat still exists within moorland cloughs but the condition is often poor and suffers damage from grazing. The location of these clough woodlands contributes to the diversity of the landscape. The dry slopes provide a contrast to the wet moorland tops and streams at the bottom of cloughs, allowing for more plant diversity.

Ash dieback has been found within the PDNP however it is currently much more of a problem in the White Peak where ash dominated woodlands are found. (see 'Limestone Dales' for more information).

Historic management of woodlands, including coppicing and pollarding has had an impact on woodland structure, leaving some woods with a lack of veteran trees and deadwood. However, these management features can also have heritage significance in their own right particularly where associated industrial and other sites remain. In other places an absence of management has led to woodland undergoing successional changes that would have previously been prevented.

As well as some mismanagement of the woodland within the valleys, people have also developed these valleys for housing, quarrying and recreational facilities. This can all lead to destruction, disturbance, trampling and pollution of these environments.

Nitrogen deposition from air pollution and nutrient enrichment from agricultural changes on nearby land have both had an impact on the woodland within the slopes and valleys of the PDNP. In particular lichen and bryophyte communities are affected by these changes.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Mature and veteran trees could be lost if storm events including strong winds increase. This could then have a knock on effect to specialist species associated with veteran tree habitat such as fungi, invertebrates and lichens. Rowan and birch could become more dominant in areas affected by damage to oak trees, changing the appearance of the landscape. **[H]**

Altered seasonal rainfall patterns could have a significant impact on this feature. Drier and warmer summers and an increase in frequency and severity of drought could impact on drought sensitive tree species especially sycamore within dry woodlands, and particularly those in shallow free-draining soils and clay soils. This is also true of ferns, bryophytes and lichens that prefer a cool wet climate. In extreme drought many trees and plants could be lost entirely. **[H]**

Increasing temperatures can also affect the **phenology** and health of woodland species; buds can burst earlier and as winters are warmer cold hardening may not happen. This could negatively affect species by risking a mismatch with other species, or by impacting those species that depend on undergoing a cold hardening process as part of their life cycle. **[H]**

In wetter conditions the ground may become waterlogged restricting the root depth for species intolerant of such conditions. Shallower tree roots may increase the risk of wind throw and exacerbate the effects of summer drought while waterlogging can also reduce soil stability. Such changes could see an increase in dominance of wet woodland species, for example alder and willow, and change the composition of native woodlands. The appearance of wooded river valleys could be changed as a result. **[H]**

The growth of trees and productivity may be enhanced by changes in atmospheric composition allowing young trees to grow quickly and increase leaf area. This could see an increase in shading and change the composition of ground flora composition and regeneration capacity. **[L]**

Invasive or other species interactions

Fewer frost events could see a greater prevalence of diseases and enable species such as deer and grey squirrel to survive in higher numbers, affecting woodland regeneration. **[H]**

Changes in seasonal rainfall patterns could see a rise in pathogens, flooding, increased fluctuation in the water table and the spread of invasive plant species. Changes to wetness can increase the impact of disease and invasive species by making trees stressed and therefore more susceptible. Invasive or nuisance plants, such as Himalayan balsam and rhododendron are a threat to the understorey of woodland. The risk is especially high for woodland located near water courses as invasive species colonise these areas easily. The number of key canopy species in woodland could be impacted which in turn could increase the vulnerability of ground flora to drought, altering the ground flora habitat composition. **[H]**

The complete loss of trees during storms or flooding events could open up bare ground increasing the risk of invasive species colonisation. Rich ground flora such as bluebells and wild garlic could be replaced by invasive species including Himalayan balsam and rhododendron. **[L]**

Higher average temperatures may lead to an increase in growth rate of riparian invasive species such as Japanese knotweed and Himalayan balsam. This could lead to the destabilisation of slopes and river banks as well as a reduction in the diversity of ground flora. **[L]**

Human behaviour change

If summers become drier, the economics of farming and forestry may change, as drier woodlands may be more suitable for grazing or forestry. In areas not protected by Site of Special Scientific Interest (SSSI) designation, woodlands may be more sensitive to both of these activities leading to damage to ground flora and the loss of species including birds and invertebrates as well as heritage assets. Such changes could affect historic woodland and reduce the visual appeal of these sites. **[H]**

Visitor numbers could increase in hotter drier summers leading to ground flora being trampled and damaged, and wildlife being disturbed. This could also lead to the loss of bird and invertebrate habitat. **[H]**

Conversely, the demand for carbon sinks through the creation or extension of woodlands, such as clough woodlands in the Dark Peak, could increase biodiversity and improve the habitat for birds such as pied flycatchers. Such a move could also improve the resilience of the landscape to erosion and flood risk, both assisting with its preservation. **[L]**

Increased demand for renewable energy may result in river flow being harnessed for energy generation. The addition or modification of reservoirs and installation of hydropower schemes (including small-scale and microgeneration) would affect the landscape, habitats and aesthetics. **[L]**

Nutrient changes or environmental contamination

Warmer temperatures may suppress the release and uptake of carbon dioxide in woodlands, as suggested by a Forestry Commission study in the south of England. Woodland could take up less carbon dioxide during the day and also release less during the night, which may have implications for tree growth. **[M]**

Lichen and bryophytes are sensitive to air pollution which could see the loss of some species and a rise in others. This could result in a minor change of appearance of these landscapes. **[M]**

Hotter, drier summers and wetter winters could see more of a change in the community composition and habitat of ground flora, lichen and bryophyte communities. This could be due to further agricultural changes to adjacent land in order to increase productivity, in particular nutrient enrichment. **[L]**

Sedimentation or erosion

An increase in evapotranspiration in hotter summers could impact ground conditions and the stability of slopes. This may cause the shrinking of clay and shale soils. If the erosion of slopes increases, run off rates may increase and vice versa. This would leading to a rise in flood risk downstream, and could alter the appearance of the landscape. **[L]**

Wetter winters could also see slopes become less stable if subject to increased hydraulic action. This could damage woodland ground flora. **[L]**

Other indirect climate change impacts

Drier ground conditions caused by hotter summers could increase the risk of wildfire. Although broadleaved trees such as oak are relatively resistant, there is a risk to ground flora and understorey. Any damage from fire could alter the habitat composition and character of woodland trees and ground flora, also leading to the loss of nesting and feeding habitat. **[M]**

What is the adaptive capacity of slopes and valleys with woodland? ***[Overall adaptive capacity rating: MODERATE]***

Generally woodlands on slopes and within valleys within the PDNP are fragmented and small in scale. Oak woods are confined to cloughs and valley sides. Connectivity varies, and is often low, reducing the adaptive capacity of this feature. However, some woodland species can exist within a wide range of elevation, habitat and isolation gradients which means connectivity between different areas should be possible and could be improved. **[H]**

Mixed species woodlands will be more resilient to outbreaks of disease and pests. Woodlands dominated by a single species such as plantations are at risk, but there are significant areas of conifer plantation that could be diversified. This work would be reliant on water companies and the Forestry Commission and could alter the contribution of this feature to its special quality. **[H]**

Environmental stewardship options and other national schemes are available for maintenance and restoration of woodland. **[H]** Organisations such as the Moors for the Future Partnership and

National Trust are able to facilitate works to increase resilience of woodland, including clough woodland establishment to increase the cover of woodland within slopes or valleys. **[H]**

Large stands of woodland are more resilient against extreme temperatures due to their cool and humid microclimate. Dry woods may have increased anchorage through the root system which grow deeper to access water or overcome potential nitrogen deficiencies. These deep roots provide stability in high winds and storm events. Woodland tree growth is limited by water availability and exposure to harsh climate, which could affect future woodland regeneration. **[M]**

Woodland can help to make the slopes and valleys more resilient to future climate changes. On slopes woodland can decelerate water flow and reduce flood damage to lower lying landscapes, while riparian woodland has the potential to reduce water temperature in summer through its shading effect. This would help to protect fish and invertebrate populations. Woodland has the capacity to reduce erosion by stabilising soils. **[M]**

Management can be undertaken to partially offset the effects of climate change stressors. Structural and species diversity can be promoted and water availability can be managed. **[M]**

Key adaptation recommendations for slopes and valleys with woodland:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Reduce grazing pressure where possible, for example reducing deer and sheep numbers to allow for more flowering and seed setting of ground flora, increasing the potential for populations to survive drought years.
- Encourage and protect regeneration where appropriate. Natural regeneration including a scrub phase will benefit biodiversity and ecosystem services. Establish significantly more tree cover in the upland valleys of the Dark and South West Peak, where appropriate.
- Consider blocking artificial drainage channels within woodland in areas predicted to become drier.
- Undertake contingency planning for outbreaks of new tree diseases.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity.
- Influence visitor and behaviour management plans and practices to minimise ignition risk.
- Include surveys for heritage significance to enable protection of the historic environment to be built into woodland management practices.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Increase structural diversity of the landscape to improve resilience to change

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Continue improving woodland condition through the careful management of plantations and more native plantings. Replace non-native conifer plantations with native broadleaved woodland.
- Encourage a greater mix of native trees through active management.
- Replace unused small plantation woodland with native broadleaf woodland.
- Increase the age structure and structural heterogeneity of woodland, for example by reducing coupe size i.e. the area harvested in one operation and encouraging continuous cover forestry rather than large scale clear felling.
- Take positive steps to increase the proportion and diversity of decaying wood throughout sites to ensure both, resilience of dependant species, and the replenishment of woodland soils' organic content.
- Allow natural woodland processes and/or woodland management to promote a diversity of age structure within woodlands. This may include retaining some undisturbed old growth stands, encouraging natural regeneration, allowing pockets of wind throw trees and deadwood, and creating a 'graduated' woodland edge as opposed to a sharp boundary with neighbouring land uses.

Adaptations that could aid other features

These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Link woodland patches together - to provide wildlife corridors.
- Increase woodland cover and the shade/shelter for other species as temperatures rise.
- When determining the optimal management of sites, consider the requirements of key species such as woodland birds to ensure minimum patch size is retained.

5.6. Habitats

Habitats

	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Acid grassland	High	High	**Moderate**	210
Blanket bog	High	Low	**Very High**	216
Heather moorland and mixed heath	High	Moderate	**High**	221
Limestone grassland	High	High	**Moderate**	226
Meadows	High	Moderate	**High**	230
Wet grassland and rush pasture	High	Moderate	**High**	236
Wet heath	High	Moderate	**High**	240
Wet woodland	High	Moderate	**High**	245
Woodlands	High	Moderate	**High**	250

Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

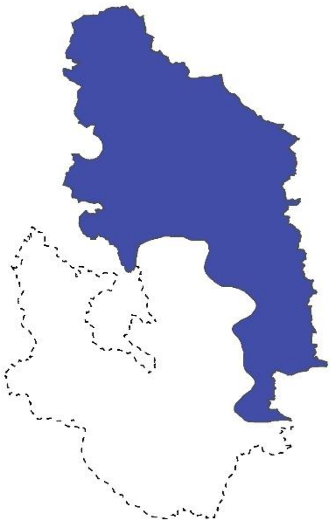
Acid grassland

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature(s) assessed:

- Acid grassland



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Acid grassland is an extensive semi-natural grassland habitat that includes a wide range of grassland types within it. It includes upland acid grassland (unenclosed) and lowland acid grassland (enclosed). Upland grassland is often dominated by mat grass and wavy hair-grass, with a few broadleaved species including heath bedstraw and tormentil. It is an important habitat for breeding meadow pipits and skylarks. Enclosed land tends to be dominated by common bent and fescue and can be species-rich with high floristic diversity in good quality grassland. It may also be important for grassland fungi, with Waxcap and other mushrooms found in high abundance in some areas (see Waxcap Fungi).

Acid grassland is found on nutrient poor soils. These are generally free draining with an acidic pH range of 4 to 5.5. It occurs on top of insoluble rocks or superficial deposits such as sands, gravels and thin peat. In the PDNP, these conditions are often found on the clough sides or below the edges of many of the heathlands and blanket bogs. Approximately 8,500 hectares of acid grassland have been mapped in the PDNP, 6,500 hectares of this being priority habitat. Around 62% of this in the Dark Peak and 31% in the South West Peak.

Lowland acid grassland is a UK Biodiversity Action Plan (UK BAP) priority. Due to the wide range of grassland types this habitat encompasses, the value and condition of these habitats varies greatly. Nearly half (42%) of mapped acid grassland in the PDNP is found within Sites of Special Scientific Interest (SSSIs) and has therefore had its condition assessed.

How vulnerable is acid grassland?

Acid grassland in the PDNP has been rated ‘moderate’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition and a high adaptive capacity.

The condition of acid grassland is variable, with some SSSI sites containing areas of high conservation value, but much acid grassland outside of SSSI designation in an unknown condition. The main impact on acid grassland will likely be a change in species composition in response to various climate change effects, either directly or in response to agricultural uses of these habitats. Livestock are a management tool for acid grassland which provide the opportunity for intervention to help this habitat to adapt to the changing climate.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Condition of SSSI sites varies between the uplands and the lowlands. In 2015 just 24% of upland acid grassland (unenclosed) in SSSIs in the PDNP was in favourable condition. The lowland acid grassland (enclosed) in SSSIs is in a better state with 93% in favourable condition. Outside of SSSI sites, the condition of acid grassland is variable.

Acid grassland vegetation structure is created and preserved by grazing. This maintains the short sward and prevents other larger plants from dominating. In the PDNP, unenclosed acid grassland is often species poor and much has probably originated through degradation of upland heath. Overgrazing is a common form of mismanagement, allowing species such as mat grass to dominate. Enclosed acid grassland is usually more diverse. Many acid grassland habitats have been lost completely to agricultural improvement.

Bracken can be a threat to acid grassland, where it is often found to spread and dominate over large areas. Many factors affect bracken spread, including depth of soil, slope aspect, altitude and steepness, with bracken generally favouring deep soils on shallow south facing lowland areas. Bracken spread has increased at a greater rate on north facing and higher altitude areas in recent years, suggesting some impact of warmer temperatures on bracken dominance.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate effects are expected to have a high overall impact on acid grasslands, including direct and indirect effects. Temperature may affect acid grasslands directly. Higher average summer temperatures and warmer winters, combined with adequate rainfall, can cause faster or extended growth of species suited to warmer climates. This could negatively affect northern or cold adapted species in acid grassland that rely on lower temperatures. **[M]**

If prolonged drought periods occur as a result of climate change then upland acid grassland in south and east margins could be affected. Flushes within these habitats would be particularly affected due to their reliance on rainfall. If these dry out then diversity here could be lost. Uncompetitive and non-stress tolerant plants that have shorter roots, such as heath bedstraw, could suffer whereas deeper rooted and/or more stress tolerant plants could be favoured. Changes in species composition may occur, with drought tolerant perennials and ruderals able to recolonise bare patches becoming more common. **[L]**

Higher temperatures and summer droughts will likely benefit winter annual plants which could result in a change in vegetation classification of acid grassland. The richest acid grasslands in the

PDNP are National Vegetation Classification (NVC) community U4. These are currently at the edge of their range requiring a mean annual maximum temperature of less than 27^{o}C and over 800mm of precipitation per year. Warmer and drier summers could shift this towards a composition more similar to NVC community U1 which is richer in annuals, or wavy hair-grass community U2. Any such shift is likely to be accompanied by a decline in perennial species associated with the more species-rich grasslands such as mountain pansy, pignut, bitter vetch, devil's bit scabious, betony, bilberry and heath milkwort. **[M]**

Higher winter temperatures could cause fewer frost days. Some annual plants depend on bare ground created by vegetation dieback for germination, a process known as frost heave. A reduction in the extent of this process could cause an imbalance between declining annual plants and perennial plants, resulting in a change of species composition. However, bare ground is created through other processes such as molehills and earthworms, as well as summer drought which is likely to become more common. The impact of a reduction in frost heave may therefore be negligible. **[M]**

Waxcap fungi can occur in acid grassland habitat and are sensitive to drought conditions. Predicted drier summers in the PDNP could cause the reduction or loss in species such as these, decreasing the species diversity and value of acid grassland. **[L]**

Human behaviour change

Agriculture has already had significant impacts on acid grassland and the effects of climate change could increase this through the opportunity for agricultural intensification. Acid grassland often occurs on the moorland edge in the Dark Peak where it can be fairly dry. Less precipitation due to climate change could dry out these habitats further, making them more accessible for livestock and farm machinery. This could expose them to agricultural intensification. **[M]**

Conversely, extreme events causing flooding or water logging of acid grassland could limit the access that farmers use for managing the land. If areas are flooded or water logged then farmers may be prevented from moving stock. This change in grazing could impact the acid grassland negatively due to the reliance of grazing to preserve vegetation structure in acid grassland. **[M]**

Another potential change to grazing regimes in acid grassland may be caused by a loss in productivity of grasses. Hotter summers may reduce soil moisture levels, causing an increase in evapotranspiration and resulting in less grass growth. Grazing of some acid grassland could be reduced to abandonment or intensified to make up the shortfall in feed. As acid grassland is dependent on grazing levels to maintain it, both would result in grassland species composition changes, leading to habitat succession and a loss of this habitat type. While this could create a more diverse mosaic of habitats which could be more ecologically valuable, the acid grassland would still be lost. **[M]**

Conversely, there is a chance that the growth of grasses would be accelerated in future climates. Faster growing and more competitive species would be better placed to take advantage of this effect and spread at the expense of slower growing species. This could lead to an increase in stocking levels and therefore increased pressure on these habitats. Species diversity could decline and the species composition may move away from acid grassland habitat, or become a less valuable type of acid grassland. **[L]**

Invasive or other species interactions

Climate change could exacerbate the invasion of acid grassland by bracken, where soils are deep enough and are unaffected by drought. Because bracken favours conditions where there are fewer frosts, warmer winters could encourage growth, expanding current stands into acid grassland habitat, and in particular could result in a spread from more sheltered cloughs and valleys onto higher and more exposed land. **[M]** If nitrogen deposition is increased as a result of climate change then this could also favour bracken growth, adding to further losses of acid grassland as above. **[L]** The possibility of drier summers could help to partially mitigate both of the above issues however, as bracken does not thrive in drought conditions. **[M]**

Nutrient changes or environmental contamination

Species diversity could also be impacted by increased nitrogen input caused by higher water input into the system during wetter winters. In the Wardlow Hay Cop study, where nitrogen was added experimentally to study plots, changes in plant frequency were seen due to acidification of grassland soils. There was an increase in grasses at the expense of other species, such as broad-leaved plants and mosses. Waxcap fungi can also be sensitive to this increased grass growth. This study would suggest that if there is an increased nitrogen input due to climate change, then acid grassland habitat could become less diverse. **[M]**

Sedimentation or erosion

It is possible that extreme events, such as storms or extreme droughts, could cause erosion on acid grassland. Landslips have already occurred after major storms in PDNP acid grassland habitat, especially where it is found on steep slopes within cloughs. Increases in such occurrences could damage the soil structure, causing a loss of habitat and opening up further opportunities for invasive species to move in. **[L]**

Other indirect climate change impacts

Hotter summers, higher average summer temperatures and warmer winters may provide longer growing seasons. Flowering times could shift, with seed set occurring earlier in the year, and a phenological mismatch could result in population changes for some insect species. A shift in plant community composition may also follow. **[M]**

An indirect impact of climate change is an increase in likelihood of wildfires due to hotter drier summers, subsequent droughts and increased ignition sources as more people visit the PDNP. While acid grassland in good condition is not sensitive to fire, it can encourage the dominance of fire tolerant species, such as bracken, heather and wavy hair grass. This could further increase susceptibility to fire and cause a positive feedback loop of an increase in these species. Invasive species could also move into the bare ground created by the fires, threatening the acid grassland habitat. **[L]**

What is the adaptive capacity of acid grassland? ***[Overall adaptive capacity rating: HIGH]***

Acid grassland has been given a high adaptive capacity rating because it can occur in a wide range of conditions and adaptation measures can be introduced, such as adjusting stocking levels as required.

The climatic envelope of lowland dry acid grassland habitat extends away from the PDNP to South East England, so should theoretically be possible for it to occur in the PDNP under all but the most extreme future climate scenarios. However, a loss or decline in some species, for example mountain pansy, may increase the fragmentation of the current extent. **[H]**

The type and composition of habitat may change within the wider acid grassland classification, resulting in losses of higher conservation value habitats but preserving the overall habitat category. While acid grassland is generally of lower conservation value and supports few threatened plant species than other habitats assessed here, in the PDNP it is especially important for internationally important waxcaps and related fungi groups. Unenclosed grass moorlands are also important for predators such as short-eared owl and hen harrier. Longer established acid grasslands are likely to be more diverse and resilient to change. **[H]**

Environmental stewardship options are currently available for the maintenance or restoration of species-rich semi-natural grassland. The habitat type can be found on land owned by a large variety of individuals and organisations. The impact of human responses to climate change – such as changes in stocking levels on acid grassland habitat is likely to have more of an impact than climate change directly. This means that it is possible to adapt stocking levels in ways that will not negatively affect acid grassland habitat, and it may be able to offset climate change at least in part. **[H]**

Key adaptation recommendations for acid grassland:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Identify areas of refugia such as north facing slopes to target conservation efforts.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Ensure key sites are in appropriate management to maximize resilience.
- Where long established grasslands can be identified, these should be a conservation priority.
- Monitor extent of bracken on important sites and ensure appropriate management to prevent spread.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Restoring the less valuable areas of upland acid grassland to heath; or scrub/woodland along edges of watercourses e.g. in upland cloughs. More trees and scrub could also reduce landslips.

Accept changes to feature

These recommendations are about adapting ways of thinking to be accepting of inevitable change. While some changes may be negative, this also presents a chance to seek out any positive opportunities that may be caused by climate change.

- Accept that some of this habitat may be lost or the structure of the habitat changed. It could become more diverse and create a mosaic of habitats, benefitting biodiversity.

Adapt land use for future conditions

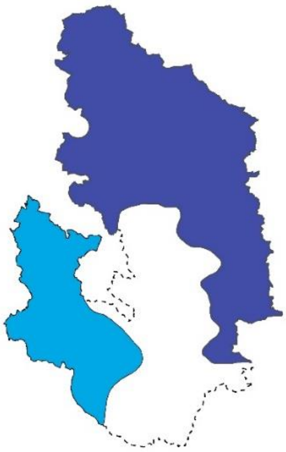
These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Adapt grazing regimes to allow for more flexibility of timing and stocking density, to ensure they are responsive to new conditions.

Blanket bog

Overall vulnerability rating:

Very low	Low	Moderate	High	**Very High**



Features assessed:

- Blanket bog/peat
- Active living bogs with *Sphagnum*
- Extensive peat deposits with pollen and fossil record

Special Qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature descriptions:

Blanket bog requires wet conditions (high rainfall and low evapotranspiration) on flat areas or gentle slopes in order to form peat, often over many thousands of years. Blanket bogs are ombrotrophic environments – depending on atmospheric moisture for their nutrient input - and when active (i.e. accumulating peat) are dominated by mire species, especially *Sphagnum* mosses. In the PDNP blanket bog is found in large areas in the Dark Peak and to a lesser extent the South West Peak totalling approximately 25,000 hectares. 19,500 ha of this being priority habitat.

These areas are nationally and internationally important, accounting for around 12% of the blanket peat soil resource in England, and being a large store of carbon. The waterlogged and acidic nature of peat means it can hold an important historical record of preserved organic material such as pollen and trees, alongside other archaeological artefacts.

How vulnerable is blanket bog?

Blanket bog and associated features in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a very poor 'non-functional' current condition, and a low adaptive capacity.

Historically in an extremely degraded condition, many areas are recovering under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations and through landscape scale conservation works. Areas undergoing conservation works are likely to be less vulnerable than those which are not; and modelling suggests that the lower altitude bogs on the eastern edge of the Dark Peak may be among the most vulnerable areas, whilst the more continuous and higher altitude areas in the north of the PDNP may be less vulnerable. The area and quality of active blanket bog in the PDNP may be reduced by climate change.

Overall impact rating: HIGH

Adaptive capacity: LOW

Current condition:

Much of the blanket bog in the PDNP is under SSSI and SAC designations. The majority of these SSSI units are categorised as 'unfavourable recovering' condition, reflecting their historically extremely degraded condition, now being addressed through landscape scale conservation works and management changes.

PDNP bogs suffered from the impacts of severe historic industrial pollution leading to low plant species diversity and a loss of *Sphagnum* mosses. Despite vast reductions in pollution, they remain highly contaminated and are still above their critical load for nitrogen oxide pollution and acidity.

Wildfires have stripped large areas of remaining vegetation, in which overgrazing and erosion have prevented recovery, resulting in a bare peat landscape – which has proved highly susceptible to further erosion. Extensive gullying of the peat blanket, along with deliberate drainage has negatively impacted its hydrological state, meaning many bogs are no longer functional and lack a capacity for resilience.

Invasive and nuisance species including windblown rhododendron and conifers are present and are able to exploit the dry conditions, and in many areas blanket bog has come to be dominated by heathland species such as heather due to managed burning. The very poor condition of PDNP blanket bogs means they are currently a source of carbon, rather than the significant carbon sink which they have the potential to be.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate change has the potential to have a severe negative impact on PDNP blanket bog, both directly and through multiple indirect effects. Blanket bog is not generally found further south-east in Europe due to its requirement for a high level and continuity of precipitation, low levels of evapotranspiration and limited seasonal temperature variability. Several of the plant and animal species it supports are at their ecological range limit in the PDNP. **[H]**

The bare peat surfaces of damaged PDNP bogs are very sensitive to direct effects of changed rainfall patterns - predicted to occur through wetter winters and an increase in frequency and severity of storm events. The impacts of such changes in precipitation coupled with increased mean temperatures and hotter drier summers are likely to lead to the dominance of non-mire vegetation (for example drought-adapted species such as common heather) changing the character of the habitat, perhaps moving further towards heather moorland. Colonisation by lowland bog species may also become more common in some areas. **[H]**

The opportunity to return degraded bogs to an active state may be lost if *Sphagnum* can no longer tolerate future climatic conditions. Where bogs are already degraded, existing gullies are likely to be widened and deepened, with new gullies and peat pipes forming. Drought conditions mean oxidation of windblown peat will increase, also further hampering or even reversing efforts to restore damaged bogs. Increased surface runoff during wet winters and storm events mean peat will continue to be lost and along with it an important archaeological record including pollen, tree remains and other organic matter. (For further information see 'Buried soils, archaeological remains and deposits'). Loss of peat will also negatively affect water quality downstream and decrease reservoir capacity through build-up of sediment. Bare peat is unable to support any macro life-forms, and the biodiversity of the PDNP is likely to be further reduced. Climate change is also likely to increase carbon release and reduce the capacity to revert the blanket bog from a carbon source to a sink. **[H]**

Human behaviour change

The most significant indirect effects of climate change may result from changes in human behaviour. Drier ground conditions caused by lower summer precipitation levels and higher average temperatures, and changes to vegetation growth rates as a result of increases in atmospheric carbon dioxide and nitrogen, for example, could lead to significant changes in upland agricultural economics. Higher livestock levels particularly around moorland edges and intensification of management practices could not only lead to changes in vegetation composition, but also to increased incidence of disease, for example *Cryptosporidium* 'Bulgy Eye' in red grouse **[M]**. Conversely, urban flooding events downstream from blanket bog watercourses may lead to a strengthening of efforts to restore bog hydrology through revegetation, damming and the creation of woodland or scrub to stabilise bog edges. **[L]**

Drought conditions and increased evapotranspiration are likely to lower bog water tables. Coupled with an anticipated increase in visitor numbers, particularly during hot summers, the frequency and severity of wildfire incidents are likely to rise. This in turn would lead to increased erosion, peat loss and uneven surfaces, making hydrological restoration more difficult than at present. **[H]**

Invasive or other species interactions

The character of vegetation present on damaged bogs is also likely to be altered by increased opportunities for invasive species and plant diseases, along with naturally occurring species such as the heather beetle. A longer growing season may give species such as rhododendron a competitive advantage (which could further increase evapotranspiration) **[M]**, and damage to the bog surface from extreme events could lead to increased opportunities for such species to occur. **[L]** Warmer wetter winters, may increase incidence of diseases such as *Phytophthora* which can impact several species including bilberry. There may also be increased survival and grazing of heather beetle which could alter landscape aesthetics. **[M]**

What is the adaptive capacity of blanket bog? ***[Overall adaptive capacity rating: LOW]***

While blanket bog is one of the less fragmented habitat types found in the PDNP, the very slow rate at which peat forms coupled with the strong geological, geomorphological and climatic constraints which limit where it has the potential to exist, mean that this habitat has a low adaptive capacity, especially within the PDNP. **[H]**

As a wetland habitat, blanket bog is reliant on almost continual water input and probably has limited ability to recover from severe drought. While different *Sphagnum* species do have differing tolerance to drought, using different strategies to do so, in its current inactive state natural recovery of PDNP blanket bog after damage (e.g. fires) without human intervention is unlikely in most locations. **[H]**

Areas which have undergone restoration work are in a better position to regenerate than the former bare peat landscape, but they still have severe lack of resilience and are very unlikely to recover well from damage compared to intact 'functioning' blanket bog. Although bogs are naturally less biodiverse than many other habitat types, historic damage means that those in the PDNP are particularly species poor and often dominated by non-mire species such as heather, or other species well adapted to fire such as purple moor-grass. This lack of species diversity, coupled with topographical uniformity (particularly on the eastern side of the Dark Peak) reduces the capacity for the habitat to adapt to future change. **[H]**

Blanket bog restoration has been supported by the UK government for over 30 years, and funding is likely to continue to be available, particularly in the light of increasing recognition of the importance of peatlands in climate change mitigation. There is a diversity of well-established institutions able to research and carry out conservation management, with a good range of different management options at their disposal. Good availability and diversity of funding, institutions, information, land-ownership and conservation management techniques, while very important for increasing potential resilience, are likely to offset climate change stressors only partially. **[H]** Further complications may arise if the current relative agreement between moorland stakeholders about the need to revegetate bare peat gives way to more disparate aspirations for the future use of blanket bog - for example grouse and sheep farming, wildlife conservation, water collection and public amenity - which may not necessarily be fully compatible. **[M]**

Key adaptation recommendations for blanket bog:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Increase effort to restore hydrology and raise the water table.
- Increase effort to revegetate any remaining bare peat areas.
- Increase *Sphagnum* re-introduction, including as diverse a mix of appropriate species as possible.
- Research is needed to look into promoting the growth of bog edge woodland or scrub where appropriate, through tree establishment and natural regeneration, to reduce wind effects, provide shade and stabilise peat blanket edges.
- Cease the use of burning for heather management on blanket bog sites – but consider alternative techniques such as cutting if there is a high fuel load (e.g. bog is or has become dry heath on peat) as an interim measure until the bog is wet enough.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity.
- More research into peat pipes is needed.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

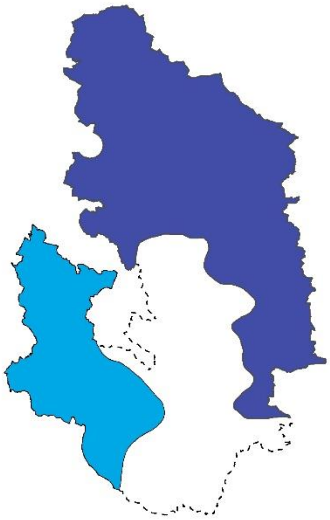
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Identify key areas to focus work on; especially those, which are likely to remain hydrologically suitable. Further study required.
- Develop visitor management plans to influence public behaviour in areas of high wildfire risk.

Heather moorland and mixed heath

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature assessed:

- Heather moorland and mixed heath

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

Heathland is found on acidic and nutrient poor soils - usually on shallow peat or podzolised soils in the PDNP. It is characterised by the presence of dwarf shrubs, such as common heather or bilberry, covering at least 25% of the area but often dominating. This category refers to those areas of dwarf shrub heath with heather dominating (commonly referred to as heather moorland) as well as mixed heath with multiple dwarf shrub species such as cowberry and crowberry and other plants such as cotton-grasses interspersed. The rarer wet heath habitat is covered in another section, as is blanket bog. Dwarf shrub assemblages growing on dry blanket bog sites are not considered.

Large areas of well-connected heathland exist in the Dark Peak and South West Peak, the majority being found in the Dark Peak. Some patches of limestone heath exist on nutrient leached soils in the White Peak, but these are small and fragmented. There are approximately 13,500 hectares in the PDNP, the vast majority of this being priority habitat.

Heather dominated moorland is common in the PDNP, partly as a result of management for red grouse shooting. Rotational burning has allowed fast growing heather to dominate large swathes of heathland. Heathland is important habitat for species such as mountain hare, bilberry bumblebee, meadow pipit and their predators, including the internationally important merlin.

How vulnerable are heather moorland and mixed heath?

Heather moorland and mixed heath in the Peak District National Park has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a relatively poor but recovering current condition, and a moderate adaptive capacity.

Current heath condition in the PDNP is generally poor due to historical stressors and poor management. Modelling suggests that areas such as Eyam Moor and heathland around Chatsworth (for example Brampton East Moor) are likely to be some of the most vulnerable to climate change due to their south-easterly location and lower altitude. Changes in human behaviour may have an important impact on this managed environment. Less biodiverse areas are likely to have the lowest adaptive capacity, meaning moorland with high heather dominance is at risk from climate change. Heathland does however have the advantage of economic and organisational resources dedicated to its conservation, and has high connectivity across large areas. Large areas are protected under Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designations. In the future, PDNP moorlands are likely to become important habitat for species that currently have a more southerly distribution, such as the Dartford warbler.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Heathland in the Peak District is generally in unfavourable but recovering condition, with some areas threatened and at high risk. This is due to multiple factors including high levels of air pollution in the recent past, habitat loss to conifer plantations and historical high levels of burning and grazing stock. Large areas of dwarf shrub heath are now protected with Special Site of Scientific Interest status as part of the Dark Peak, Eastern Moors, and Leek Moors SSSI areas, and large areas have Special Area of Conservation designation as part of the South Pennine Moors SAC.

Despite vast reductions in air pollution, the legacy of industry is still present in the form of heavy metal ions and increased nitrogen levels in the peat. Bare ground and increased nutrients have allowed generalist colonisers such as rosebay willowherb to move in. Nitrogen deposition especially is damaging to the low nutrient environment, causing root damage to heather and increasing its susceptibility to heather beetle infestation. The native heather beetle is a persistent presence and affects some areas. Its impact is greatest in areas of high heather densities, but small outbreaks may in fact help to diversify the species richness and age structure of the vegetation.

Much of the heathland of the PDNP is managed for either grouse shooting, sheep farming or both. In the past, overgrazing, wildfire, and war activity (such as firing practice on Bradfield) led to problems such as lower plant diversity, changing dwarf shrub extent, and the opening up of bare ground which facilitated erosion. Without appropriate management, heath is invaded by willow and birch scrub, and may begin to succeed to woodland. This can be seen on some sites, such as lower Woodhead Moor and Dove Stone.

The popularity of the moors for leisure can also cause problems. Path erosion, both from heavy footfall and vehicle damage, is a continual though localised issue. Areas with high visitor numbers, such as those close to the cities of Sheffield and Manchester, are also at much greater risk of wildfire due to arson and accidental ignition, especially by highly portable and very flammable disposable barbeques. Wildfires have historically burnt large areas of heather moorland, and will likely continue to do so.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Climate change may have a variety of effects on heather moorland and mixed heath. Some of these effects may act to break heather dominance, or remove dwarf shrubs entirely, causing changes to the composition and diversity of this habitat. As a habitat that is in large part sustained by human intervention, some of the risk will be from changes in human behaviour as a result of climate change.

Direct impacts of climate change

Changes to annual precipitation patterns are a risk to heathland communities. Waterlogged conditions in winter can cause anoxic conditions in the soil, leading to root dieback. Dwarf shrubs are particularly susceptible to this, although the well-draining nature of heathlands in the Peak District will reduce the effect. Summer droughts may also cause increased sensitivity of heather to heather beetle and loss of less drought tolerant species such as crowberry. **[H]**

Increased winter rainfall may lead to higher levels of nitrogen deposition in the uplands if atmospheric nitrogen levels do not decrease. Excess nitrogen input increases sensitivity of heather to drought, frost, and heather beetle outbreaks**.** Heather growth could become stunted, which would change habitat density and character. Community composition could be altered, with heather dominance decreased. Provided the plants were replaced by other dwarf shrubs, this could be beneficial to the community resilience. **[M]**

Higher annual temperatures will likely lead to a longer growing season for moorland plants, giving more competitive plants such as some grasses an advantage over slower growing species such as heather. This could cause heathland community composition to move towards an acid grassland assemblage and therefore some may be lost. **[M]**

Other indirect climate change impacts

A hotter, drier climate is expected to heighten the risk of wildfire. This will not only increase erosion and remove habitat in the short term, but in the long term will encourage heather or purple moor-grass dominance and possibly open up bare ground for fast colonisers such as bracken to invade in some places. **[H]**

Changes in climate may lead to loss of key species as the habitat becomes unsuitable for mountain hare, and birds such as red grouse, merlin, ring ouzel, and twite, as well as altering food web interactions**.** Potential gains may be seen in other species such as nightjar, stonechat, hobby, and Dartford warbler. Phenological changes (changes to the timing of natural events) may lead to decreased numbers of key species such as the invertebrates which many species depend upon. **[M]**

Human behaviour change

Increased visitor numbers due to hotter, drier summers may exacerbate problems already present at popular sites. Higher footfall will lead to greater path erosion, as well as increased disturbance of ground nesting birds. The wildfire risk associated with popular sites is likely to increase, especially in hot, dry conditions. **[VH]**

Future changes in management will have important consequences for heathland, especially heather moorland. Usual management actions may be disrupted by changing weather conditions. Spring heather burning is likely to have an increased risk of out of control blazes due to the earlier dry season. Autumn heather cutting could also be hampered due to earlier rains causing wetter ground conditions and bogging down cutters. It is feasible that this may lead to cessation of management in some areas, allowing birch and willow scrub to encroach and the habitat character to change. A shifting climate envelope for some species, such as red grouse, may also lead to changes in moorland management. **[M]** Conversely, increased productivity due to greater grass growth could potentially lead to more grazing land use. Higher stocking levels, increased erosion and nutrient loading could potentially shift the community composition towards acid grassland. **[L]**

Invasive or other species interactions

Warmer conditions may lead to greater populations of species such as heather beetle and *Phytophthora.* **[H]** The effect of these pests would be greatest in areas with high heather or bilberry dominance. Community composition could be altered, with other heathland species outcompeting stunted heather and bilberry. In extreme cases, the bilberry component of the habitat could be lost, threatening the continued survival of bilberry dependent species such as bilberry bumblebee and green hairstreak. **[M]**

Higher temperatures, especially warmer winters, are likely to create more suitable conditions for bracken to colonise heathland. Heath at higher altitudes will be at risk of bracken invasion, which may replace heather in some cases and cover large areas. **[H]**

An increase in winter rainfall, particularly during storm events, may have important consequences for heathland. Heavy rain and severe winds damage plants, and increased runoff can cause soil erosion. As heathland in the PDNP is often on mineral soils or thin peat soils less than 40 cm deep, such erosion can lead to root damage, although the effect may be reduced by existing drainage. Root damage increases susceptibility of dwarf shrubs to winter desiccation, meaning community composition may be altered. **[H]**

What is the adaptive capacity of heather moorland and mixed heath? ***[Overall adaptive capacity rating: MODERATE]***

Resources are available for the management and restoration of heathland through multiple sources. Environmental stewardship options are available to individual landowners that have an interest in conserving their land. **[H]** There are also many organisations operating in the PDNP that can conduct or facilitate works to increase the resilience of heathland including Moors for the Future Partnership and The National Trust. **[H]** However, although management action can be taken to partially offset the effects of climate change, there is limited agreement about future land use due to the conflicting interests of different stakeholders; the aims of conservation organisations potentially conflict with those of landowners managing their land for sheep farming or grouse shooting. **[M]**

Heather regrows and spreads relatively quickly, so can react to change and recover from damage, although this may be at the expense of other plant species, increasing its dominance and reducing diversity. **[M]** Less mobile species such as *Sphagnum* may be restricted to their original sites and unable to adapt to change. **[H]** The seed bank may be vulnerable to erosion if left exposed, meaning recovery may be slower with increased erosion. Heather brash and plug plants of dwarf shrubs are currently used for revegetating sites, so it is possible to assist with recovery from damage. **[M]**

Both the large size and variability in topography and habitat mosaic provide some resilience for PDNP heathland. **[H]** Large areas dominated by heather are more vulnerable than mixed heath areas, which will be more adaptive to change. Upland heath grades into lowland heath and blanket bog, and so heathland overall is relatively diverse and resilient along climactic gradients. **[H]**

Key adaptation recommendations for heather moorland and mixed heath:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Continue program of moorland rewetting.
- Identify sites within the uplands that can act as climate change refugia due to complex micro-topography, robust hydrology, and high species diversity, and manage these accordingly.
- Minimise erosion through management of access, appropriate grazing levels, and reduction of burning.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity.
- Bracken may need to be controlled through grazing and other management.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Increase the diversity of heather dominated areas - adapt to mixed heath.
- Maintain and enhance structural diversity within heathland vegetation, including wet heath patches, diverse age classes of dwarf shrubs, and scattered trees and scrub.
- Continue clough woodland creation/restoration to increase scrub and woodland cover within upland mosaic which will help improve habitat heterogeneity and provide refugia for sensitive plants and invertebrates.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Develop visitor management plans to reduce fire risk on areas of high wildfire risk.
- Cease the use of burning for heather management on vulnerable sites – but consider alternative techniques such as cutting.
- Strengthen footpaths and manage increased visitor access to minimise disturbance in key areas.

Adapt land use for future conditions

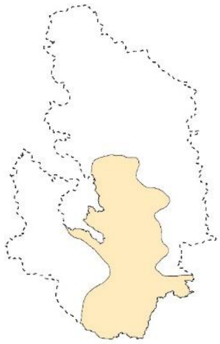
These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Adapt management intensity to changing characteristics of heather moorland – alter grazing pressure, types/breeds of livestock, and burning/cutting cycles to suit future climatic conditions.
- Consider that designated natural and cultural site features of interest may change.

Limestone grassland

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Limestone grassland

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- An inspiring space for escape, adventure, discovery and quiet reflection

Feature description:

Limestone grasslands - dominated by herbs and grasses - are found on base-rich, thin and well-drained soils overlying limestone geology. In the PDNP, around 1,200 hectares of limestone grassland has been mapped, all of this being priority habitat. The vast majority (98%) is found in the White Peak. This relatively small extent covers less than 5% of the area of the White Peak – mostly designated as Sites of Special Scientific Interest (SSSIs) and Special Area of Conservation (SAC).

Smaller undesignated areas are often confined to steeper slopes or rocky outcrops on the limestone plateau. The limestone grasslands that remain in the PDNP are internationally important - supporting a large diversity of species.

They support many rare plants including pyramidal orchid, spring cinquefoil and probably the largest British population of Jacob's-ladder as well as butterflies such as the brown argus, dingy skipper and dark green fritillary.

How vulnerable is limestone grassland?

Limestone grassland in the PDNP has been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but also a high adaptive capacity.

Limestone grassland in the PDNP has a limited extent, but much of what remains is protected by SSSI designation. Overall habitat persistence is likely to be determined by non-climate or indirect human factors, for example changes in agricultural economics, with areas such as the dales likely to be impacted. The iconic Jacob's-ladder grassland may be particularly vulnerable and in need of conservation actions.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

A large proportion of the remaining limestone grasslands in the PDNP are classified as SSSIs, and in 2015, 58% of these protected sites were categorised as being in favourable condition. In unprotected areas, condition is more variable. Changes in levels and types of livestock are likely to have affected the quality and extent of the habitat since the 1940s. Increases to the periods in which livestock are housed, and a shift from sheep farming in the dales to dairy farming on the limestone plateau, may have affected the availability of suitable stock needed to maintain the habitat. Losses of limestone grassland to scrub encroachment (through lack of grazing) are known to have been significant, and a number of sites have probably been lost to plantation woodlands. Increases in plants such as thistles, docks, and nettles may have been exacerbated by disturbance and high nitrogen deposition, and non-native invasive species such as Himalayan balsam have spread into areas away from rivers.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate change has the potential to have several negative impacts on PDNP limestone grasslands. Although the UK distribution of limestone grassland reaches further south and east than the PDNP (to areas with a hotter, drier climate) those within in the PDNP currently support several species of plant with a northern distribution – for example globeflower, melancholy thistle, mossy saxifrage and the Derbyshire County Flower Jacob's-ladder. Therefore, although limestone grasslands are unlikely to be completely lost over the next century due to direct climate effects, they are likely to undergo changes in character and composition. **[H]**

Hotter drier summers are likely to change the species composition of PDNP limestone grassland communities. Northern and upland compositions such as the National Vegetation Community (NVC) CG10, which is thought to require a mean maximum summer temperature of less than 24^{o}C, may move towards southern and lowland compositions such as NVC CG2. Community composition changes may be greater on south facing slopes that receive more sunlight. **[H]**

Similarly, NVC MG2 (tall dales grassland with Jacob's-ladder) is thought to require 900 - 1650 mm of rain per year and more than 180 wet days, and may be the most vulnerable grassland community in the dales. This could shift towards NVC community MG1 (the mesotrophic *Arrhenatherum elatius* grassland) with the loss of species including the iconic Jacob's-ladder. **[H]** In addition, species which need frost to germinate (vernalisation) such as cowslip and yellow rattle are likely to decline as winters warm. **[H]**

Drier summers mean that specialist mosses and fungi could also decline (see also 'Waxcap fungi') and deep-rooted stress-tolerant plants may become more dominant. Annual plants may benefit more than perennials – this can already be observed on south facing slopes in the Dales. **[L]**

Invasive or other species interactions

Increased levels of nitrogen may provide better conditions for species such as thistles and nettles, which in turn could lead to an increased use of herbicides. **[M]** In combination with increases in temperature, nitrogen deposition could potentially result in a higher proportion of grasses and fewer broadleaved species especially in areas which remain wet. Drier conditions, however, may help with the control of invasive species such as Himalayan balsam. Conversely increases in flooding events may spread seed from invasive species into new areas, while summer droughts and more extreme weather events may open grass swards and create more opportunities for invasion. Some rare winter annuals such as *Hutchinsia* may also do better. **[L]**

Human behaviour change

Changes to agricultural economics are difficult to predict, but have the potential for a major impact. Wetter winters may mean that livestock is increasingly housed over winter, while summer droughts may cause some areas to be unsuitable for grazing. The resultant changes in grazing regimes could cause a loss in some floristic elements, or even the loss of the grasslands through scrub invasion. **[H]**

What is the adaptive capacity of limestone grassland? ***[Overall adaptive capacity rating: HIGH]***

Limestone grasslands occur in a wide range of conditions and latitudes across the UK, with the lowland calcareous grassland climatic envelope going well south and east of the PDNP, although some key species are already at their southern range limit. Therefore, the overall habitat category may change in character and composition but is unlikely to be lost altogether. However, some already scarce types such as NVC CG10 (dales limestone grassland - northern type) and MG2 (tall dales grassland with Jacob's-ladder) may be particularly prone to decline and increased fragmentation.

The current extent of limestone grassland in the PDNP is somewhat fragmented with limited connectivity, and is restricted to the White Peak. Natural England habitat opportunity map modelling shows areas of fragmentation for this habitat type. The dales are currently highly fragmented with a huge edge-to-surface ratio making them very vulnerable to adjacent agricultural activity.

Limestone grasslands, especially those that are longer established, have been shown to be relatively tolerant to atmospheric pollution and acidification, in part due to the base-rich soils on which they are found. Research shows that the dales may be important refugia sites for some species, with the diverse topography allowing some species to survive in "cool spots" such as north facing slopes. Coupled with the high species diversity, these factors provide more potential for habitat persistence and adaptation.

A large amount of the remaining limestone grassland in the PDNP is already protected (mostly as SSSIs), and existing work to improve condition has already contributed to safeguarding what remains against non-climate threats. Whilst improving condition cannot protect from climatic extremes, it should increase general resilience to change, and may partially offset some climate stressors. In addition, Environmental stewardship options are currently available (and likely to remain available) for the maintenance or restoration of semi-natural grasslands. Since these grasslands are managed habitats, human responses are likely to have a stronger influence on habitat persistence than the direct results of climate change, and therefore there is good scope for making adaptations.

Key adaptation recommendations for limestone grassland:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- There is scope for expansion of limestone grasslands onto some parts of the plateaux where limestone is close to the surface or exists as outcrops. Where expansion is limited by underlying geology, grading into continuous neutral grassland, heathland or scrub should be encouraged.
- Adapt management to avoid fertilizer inputs.
- Reduce non-climate sources of harm.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Grassland in greatest need of considering conservation options further is perhaps MG2 Jacob's-ladder grasslands.
- Restore priority areas where scrub has encroached, but maintain some scrub in the landscape.
- Work to identify the best refugia sites and ensure these are managed appropriately.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Increase size and connectivity of existing patches, including connectivity with other habitat types in a mosaic.
- Increase connectivity by restoring species rich grassland. This should also increase resistance to drought and increase carbon capture.
- Increase wood pasture on the plateau. Increase trees in fields and along margins to help with summer drought and forage for stock.
- Have an integrated management plan for each of the Dales in the PDNP for the different habitats within them.

Adapt land use for future conditions

These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Adapt grazing regimes to allow for more flexibility of timing and stocking density.

Accept changes to feature

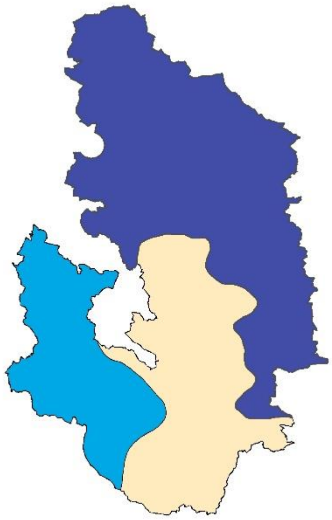
These recommendations are about adapting ways of thinking to be accepting of inevitable change. While some changes may be negative, this also presents a chance to seek out any positive opportunities that may be caused by climate change.

- Loss of some currently valued northern species but gain of more southern species may need to be accepted. Liaise with other protected landscapes (such as those further north) to share knowledge and management techniques.

Meadows

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Meadows and flower-rich grasslands
- Wildflower meadows
- Hay meadows
- Unimproved pastures and meadows (and road verges)

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

The ‘meadows’ category is comprised of unimproved lowland (mostly neutral and enclosed) grasslands across the PDNP. It focusses on wildflower rich areas and those cropped for hay in particular, but also applies to flower rich pasture and non-agricultural settings which may be rich in wildflowers such as roadside verges or church yards.

Approximately 1,700 hectares of lowland meadows are mapped – representing only 1.2% of the area of the PDNP. These meadows are all considered priority habitat in the PDNP. Approximately 70% of what remains can be found in the White Peak, 20% in the South West Peak and 10% in the Dark Peak. Of the total area recorded, around 50% has been categorised as hay meadow.

The PDNP hay meadow survey found there to be six community types in the PDNP, but there is potential for more discoveries to be made as only some meadows in the South West and Dark Peak were surveyed. Of the known communities, some, such as flood plain meadows, represent only a few fields making them rare in the PDNP.

Meadows are an important feature for biodiversity. A meadow in good condition can contain more than 50 plant species as well as provide habitat for mammals, invertebrates, and rare and declining bird species such as skylark and twite. Meadows are rich in grass and grass-like species as well as flowering broad-leaved herbs, and provide a vital refuge for biodiversity in an agricultural landscape, breaking up areas of silage fields and adding diversity to the landscape mosaic. Hay meadows are also a traditional feature of the landscape with ancient cultural significance, and may even predate churches in some villages.

How vulnerable are meadows?

Meadows and associated features in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a varied current condition and highly fragmented habitats, but with a moderate adaptive capacity.

Meadows are already in a poor state in the PDNP, with only a few small patches with very limited connectivity remaining. Climate change impacts are unavoidable; key plants and their associated species may be lost. Some meadow species will be unable to thrive with changes in weather, leading to habitat change. Agricultural intensification caused by pressure to grow more food may lead to further habitat loss. A mismatch between flowering and pollination timings may lead to a decrease in some plants. Pollution may cause changes to soil composition. Hay-making may become difficult due to unpredictable weather. Overall, climate change stressors are likely to lead a loss of habitat and biodiversity.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Meadows are in very poor condition nationally, with a 97% decline in flower-rich grasslands between the 1930s and mid-1980s almost wholly due to changes in agricultural practices. This loss has continued in the PDNP, the Hay Meadows Project recorded a 50% loss between the mid-1980s and mid-1990s with a further 26% declining in interest, and then a further 25% loss or quality decline between 1995 and 1998. The rate of loss has varied greatly, but intensification of dairy farming has been identified as a leading factor in areas such as Peak Forest. Only a very small portion of the meadows present 80 years ago remain.

The habitat has become highly fragmented and localised across the whole of the UK including in the PDNP. There are few surviving flower-rich hay meadows which support species such the as oxeye daisy and yellow rattle. Some areas of meadow are protected as Sites of Special Scientific Interest (SSSIs) in the PDNP, but many meadows are not covered. Condition is variable even within SSSI sites, and data is limited for those areas not covered by SSSI designation or owned by a Non-Governmental Organisation (NGO) such as National Trust or a County Wildlife Trust, though many are covered by environmental land management agreements. Meadows in the limestone dales are generally in better condition and have higher connectivity, but these areas are still relatively small.

As meadows are a habitat created and maintained by human intervention, changes in management have a great effect on their condition. There has been a change towards silage making rather than haymaking, a technique that promotes vigorous grass growth through multiple cuttings, often supported by fertiliser and broadleaved herbicide. Much of the floristic diversity of unimproved meadows is then lost in as annuals are prevented from setting seed and broadleaved herbs are eliminated. This is a direct cause of the catastrophic loss of meadowland over the past 80 years, and continues to be a risk for unprotected sites. Meadows have also been lost to pasture land, in which livestock are not removed during the main growing season or where there is increased use of fertilisers and herbicides, leading to a reduced sward height and loss of broad-leaved herbs and lower plant diversity.

Fast growing ruderal species such as hogweed, spear and creeping thistle, cow parsley, and nettle can dominate areas of meadow. Though these are native species and have a place in the grassland assemblage, their tendency to dominate has led to their status as weeds. These species are particularly prevalent on fertilised sites, as excess nutrient input allows them to outcompete other broadleaved plants. Roadside verges which could harbour meadow species are also prone to invasion of this kind due to their disturbed nature and poor management, combined with the addition of nitrogen which is greater along roads with more traffic.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Changes in annual precipitation cycles could have consequences for meadow plant communities. Waterlogging in winter and dry ground in summer would give a competitive advantage to stress tolerant and ruderal plants. Characteristic meadow species that are particularly drought sensitive such as red clover could be lost from some meadows. This happened in some areas during the hot and dry summer of 2018, particularly on south facing slopes in the first instance. Higher spring soil moisture levels may also increase total biomass and favour more competitive species such as grasses, at sites where phosphorus in not a limiting factor. These effects could combine to change the composition of some meadows, with some species dominating at the expense of the usual assemblage. **[H]** These effects could be compounded by an increase in winter storms and summer droughts, causing ground conditions to more often be at extremes of moisture. Increased flooding could be particularly damaging to floodplain meadow communities, which are vulnerable to larger and longer flood events. This could cause floodplain meadow communities to transition to low diversity swamp or inundation grassland communities. As there are only a few sites in the PDNP, this could cause them to be lost entirely. **[L]**

Earlier warm conditions may change the phenology (timing of natural events) of some meadow plants, causing them to flower and set seed earlier. This may lead to phenological mismatches such as reduced pollen and nectar availability for invertebrates and reduced seed availability for bird species. Higher temperatures and a longer growing season may also give a competitive advantage to fast growing species, reducing the diversity of meadows in some areas. Higher temperatures will move the climate envelope northwards, meaning some species at the southern edge of their range may decline, while southern species that are capable of long-distance dispersal expand their range northwards. Warmer winters will also reduce vernalisation, a process by which the prolonged cold of winter is a cue for winter dormancy and spring flowering in some plants. Species that require vernalisation such as yellow rattle and cowslips may therefore be disadvantaged and outcompeted by species that do not. **[H]**

Increased winter rainfall may lead to higher deposition rates of nitrogen, and other atmospheric pollutants could cause increased acidification. Acidification can have a variety of effects, including increased concentrations of toxic ammonium, increased solubility of aluminium and other toxic cations, and reduced phosphorous availability. These effects combined would disadvantage sensitive plants, reducing the floristic diversity and value of meadows. However this may be offset be landowners adding more lime to maintain existing plant cover. **[M]**

Human behaviour change

Haymaking practices could be affected in numerous ways, but the increased variability of weather makes this hard to predict. Traditional haymaking relies on warm, dry, settled weather to facilitate the drying of hay after cutting, and it is here that there is uncertainty as to the effects of climate change. Climate change will mean warmer, drier summers, which could make haymaking more viable as drying hay becomes easier. Haylage, in which hay is not left to dry for as long, would also be affected to a lesser extent, potentially making it more desirable than silage making. **[M]** However, extreme weather events such as storms are also predicted to become more frequent, meaning that unpredictable heavy rainfall may prevent or delay haymaking, reducing its already limited economic viability. **[M]** Increased productivity due to increased temperatures could also cause a reduction in hay meadow diversity over time due to change in management. More productive meadows may be cut earlier, before seed is set, preventing annual regeneration. **[M]** Drier summers may also mean that some sites are abandoned due to the crop dying off prematurely. Cessation of management would mean that some meadows are lost as they succeed to other grassland or woodland habitats, or a different management regime is taken up. However, reduced management of fields in other areas may allow some natural meadow generation. **[H]**

Wetter, warmer springs causing increased vegetative growth in areas that are not nutrient limited could make frequent cutting desirable for landowners. Frequent cutting encourages grasses to dominate, reducing the species diversity and changing the community composition. This effect is especially pronounced when cuttings are left to lie, creating thick ground cover and increasing the nutrient input from the dead plant matter. This practice is common on verges, where sward heights may regrow more quickly and ruderals such as rosebay willowherb move in to disturbed areas and dominate, boosted by the additional nitrogen input from traffic. **[H]**

Warmer weather earlier in the year may mean that cutting dates are also earlier. This would have a negative impact on ground-nesting birds on undesignated sites, as some may still be breeding or nesting, and would be negatively affected by machinery and disturbance. As silage cutting makes much farmland uninhabitable, disturbance at those sites remaining could be quite damaging. **[H]**

Changes in water usage could have a large impact on floodplain meadows, particularly in lower areas of the PDNP. While there are controls in place, increases in water abstraction during dry spells could dry out some sites and change their community composition to more similar non-floodplain meadow types. **[M]**

Invasive or other species interactions

Changes in water levels are likely to increase the sensitivity of meadows to dominance by generalist and ruderal species by increasing disturbance. Summer droughts leaving bare ground could magnify this effect, opening up space for ruderals to colonise. Community composition would be altered as less competitive species, including many characteristic meadow species, are replaced by generalist meadow species or opportunist ruderals and invasives. **[M]** Riverside and floodplain meadows are also at increased risk of colonisation by invasive species such as Himalayan balsam as winter flooding could spread seeds over large areas. **[H]**

Nutrient changes or environmental contamination

Increased flooding in riverside meadows could cause an increase in nutrient deposition. Nitrogen and phosphorous enter the watercourse via pollution in runoff, and can be deposited onto meadows during flood events. Increased nutrient availability could provide an advantage to faster growing plants such as grasses, pushing out some meadow species and changing community composition. **[M]**

Sedimentation or erosion

Higher flows during winter could cause greater erosion in meadows, particularly those near waterways. This effect could be compounded by the presence of Himalayan balsam on riverbanks, which dies back in winter leaving the ground bare and the banks more vulnerable to erosion. This would lead to losses on the edges of meadows and a reduction in habitat. Wetter soils are also more sensitive to trampling, increasing erosion in waterlogged conditions, which will be more prevalent in wetter winters. **[M]**

What is the adaptive capacity of meadows? ***[Overall adaptive capacity rating: MODERATE]***

Meadows in good condition are very diverse in plant species, with the best holding well over 50 different plant species. This diversity means that the small number of meadows currently in good condition will have the highest ability to resist or adapt to the effects of climate change. It must be accepted that some northerly-distributed species, such as great burnet and lady's mantle, will decline or be lost from some sites. **[M]** However, meadow assemblages can vary, with the broad requirements of a meadow simply being a high diversity of grass-like and broadleaved herbs. Therefore, while some species may be lost from meadows and the community composition changed, meadows themselves are unlikely to be lost. Some species that are lost, for example those at the southern edge of their range, may be replaced by other species that fill their niche, such as other generalist species in the sward or southern species with northern range expansions. **[H]** Meadows in the PDNP are generally highly fragmented with low connectivity, so this replacement of species and gradual shift in diversity would be slow. **[H]**

Meadows have some level of protection though designation and ownership. Some are owned by the National Trust, PDNPA, County Wildlife Trusts or a few are designated as SSSIs, and many in private ownership have an environmental land management scheme aimed at maintenance or restoration. **[H]** Although PDNPA can make recommendations on meadow management, it has no statutory capacity to enforce management on privately owned land, although private land is still covered by Environmental Impact Assessment regulations and has some level of protection. **[M]** As a managed environment, meadows have the advantage of management adaptation to withstand some climate change effects. However, this may be difficult to practically implement due to the currently low economic incentives to create and maintain meadows.

Key adaptation recommendations for meadows:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Many more restored meadows are needed in the PDNP if effective nature recovery networks are to be developed. These would increase carbon storage and capture, increase resilience to climate change and drought especially, provide transitional sites between existing habitats, plus better habitat for invertebrates and other animals. Species rich meadows are much better for a healthy stock animal as well – though less productive than heavily fertilised pastures, they provide a more diverse, healthy diet, better ways of managing health – many old ones were called hospital fields, and are essential for a low input low output system.
- Opportunities to extend and enhance the management of existing unimproved grasslands should be sought, for example in "Riverside Meadows" where grasslands could enhance their role for flood water storage, helping to reduce flood impacts further downstream.
- Encourage the creation and enhancement of wildflower meadow in non- agricultural settings e.g. recreational areas, churchyards, verges and residential gardens. A scheme to help with conversion or management may be required.
- Non-climate sources of harm (for example conversion to silage or permanent pasture; application of high fertilizer levels, early cutting) should be minimised to ensure maximum possible resilience.
- Identify and preserve refugia for species at their southern range limit - look at aspect and topography and ensure sites are sensitively managed.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Species rich meadow should be one of the key habitats to be considered when other habitat types are no longer viable due to climate change. Rush-pastures which have become too dry could be converted.

Adapt land use for future conditions

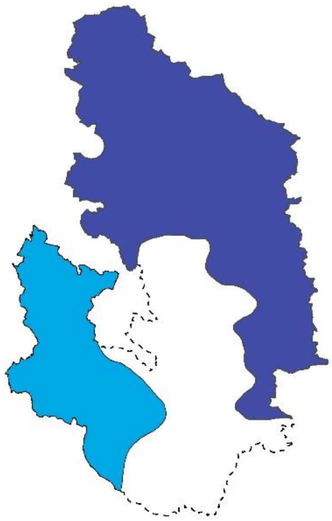
These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Greater flexibility in site management will be needed - e.g. Timing of hay cut and grazing.

Wet grassland and rush pasture

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature assessed:

- Wet grassland and rush pasture

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats

Feature description:

The habitats considered for this assessment fall into two main categories. Firstly, areas of moorland dominated by purple moor-grass – often blanket bog or heath which has been invaded as a result of regular burning over wet soils. Much less extensive however is rush pasture. Occurring on wet and infertile soils, it contains a mixture of grasses (including purple moor-grass), sedges, rushes and also some broadleaved species. Wet grassland and rush pasture covers approximately 1,550 hectares in the PDNP, 250 ha of this being priority habitat. They can be important habitats for many invertebrate species, and also several species assessed in this report (see short-eared owl, curlew, snipe and lapwing).

How vulnerable is wet grassland and rush pasture?

Wet grassland and rush pasture in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, the fragmented nature of the more rare and biodiverse rush-pasture type habitats, coupled with a moderate adaptive capacity.

Mismanagement and drainage has resulted in many areas of wet grassland becoming species poor, some being dominated by purple moor-grass. The reliance of these grasslands on water input coupled with the economically uncertain nature of upland farming mean that climate changes have the potential for large direct and indirect impacts.

However, through environmentally sensitive management and restoration of water tables it should be possible to partially offset some of these impacts. The key adaptation measures are to join up and enhance remaining fragments of rush pasture where it is possible to maintain or increase water levels; and to accept that some areas may need to be converted to other habitat types such as flower rich meadows. The diversification of the sward in purple moor-grass dominated blanket bogs through the reintroduction of *Sphagnum* mosses should increase the biodiversity and the future resilience of these wetlands.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Whereas purple moor-grass dominated moorland can be found in relatively large blocks, the remaining rush pastures in the PDNP are now fragmented, with loss being due to agricultural improvement such as drainage and application of fertilizer or inappropriate management such as overgrazing or abandonment. Where moorland habitats have been managed inappropriately, they have often become dominated by purple moor-grass to the exclusion of almost all other plant species.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

These habitats are sensitive to changes in soil moisture, so there is a potential for shifting patterns of precipitation and changes in temperature to have a significant effect. Increased spring soil moisture levels coupled with higher temperatures could lead to an increase in vegetation biomass, which in turn could lead to changes in human behaviour such as altering livestock levels. Increased stocking can lead to detrimental effects such as soil poaching, increasing dominance of soft rush and other stress tolerant plants. **[H]** Early growing species may begin to dominate the plant communities, while later flowering plants such as devil's bit scabious may be reduced. **[L]**

Similarly, drier summers and drought periods may lead to drier soils and a change in habitat composition, such as a move toward acid or species-poor neutral grassland. Richer rush pastures may become less diverse with a resultant impact upon invertebrates and their predators. Breeding waders are likely to be impacted by a reduction in the availability of invertebrates. This may also affect thrush species such as ring ouzel during the spring and summer, and autumn migrants such as redwing and fieldfare later in the year. **[H]** Conversely, increased waterlogging due to wetter winters and increased periods of flooding could lead to colonisation by ruderal species such as soft rush and ultimately a change towards species better able to cope with inundation. **[H]** Increased atmospheric carbon dioxide may affect the soil chemistry and productivity of plants and therefore change interspecific competition, potentially leading to the loss of the less competitive species. **[L]**

Human behaviour change

Hotter, drier summers resulting in drier ground conditions may enable changes to the way rush pastures are farmed. The altitude of land suitable for in-bye may increase, and it is possible that some areas will become suitable for easier drainage, more intensive grazing regimes or even arable use. This could lead to a loss of habitat for invertebrates and feeding opportunities for birds - particularly waders. **[H]** Due to drier ground conditions, purple moor-grass dominated moorlands may also be more susceptible to damage from wildfire, the human ignition sources of which may also increase. However, wildfire on purple moor-grass dominated moorland is more likely during spring when the deciduous leaf blades are dead and dry. Prolonged drought is less likely earlier in the year, and the wet nature of this habitat likely reduces this risk significantly. **[L]**

Wetter winters may lead to stock exclusion during winter and spring if land becomes too saturated or waterlogged to either graze or access **[H]** leading to abandonment of certain areas as pasture. A longer sward in the spring may disadvantage ground nesting birds such as lapwing. However, reduction of soil compaction during wetter periods could be benefit soil invertebrates and have knock on effects on their predators.

Invasive or other species interactions

Increases in severity and frequency of flooding events in summer and winter may lead to increased disturbance of ground cover and therefore opportunities for invasive species to spread. While wet grasslands are currently not particularly prone to invasion, climate change may mean species such as Himalayan balsam are able to dominate in some areas. **[M]** Changes in carbon to nitrogen ratios in plant leaves may enhance their nutritional value resulting in an increase in herbivory. **[H]**

Nutrient changes or environmental contamination

Wetter winters and flooding events may lead to nutrient loading of some sites, depending on surrounding land use and topography. This may mean that vegetation types adapted for low nutrient input are impacted and species composition may change. **[M]**

What is the adaptive capacity of wet grassland and rush pasture? ***[Overall adaptive capacity rating: MODERATE]***

Both types of wet grassland covered here require some form of active management, so it is possible to vary their management – for example by ensuring a more appropriate or flexible grazing regime - in order to ensure they are as resilient to climate change as possible. In the case of rush pastures this could involve ensuring that low intensity grazing or appropriate cutting is implemented, whereas in the case of purple-moor grass dominated moors this may involve the diversification of the sward and species in an attempt to move towards a more heterogeneous habitat.

Purple-moor grass dominated moors cover large continuous areas, whereas rush pastures in the PDNP cover a much smaller area and are more fragmented. The remaining fragments and the species they support are less likely to be adaptable to climate change, and are unlikely to adapt well to a severe decrease in wetness. However, these habitat types can occur on a wide range of soils ranging from acid to alkaline and there is a good potential for wet grassland habitat creation alongside restoration and sensitive management of existing areas.

Environmental stewardship options are currently available for the maintenance and restoration of wet grassland and within the PDNP there are several organisations which have the potential to help landowners to drive forward suitable adaptive measures including the PDNP Partnerships (Moors for the Future Partnership and South West Peak Partnership), and Non-Governmental Organisations (NGOs) such as National Trust and RSPB. There is potential for some of these areas to become the focus of Natural Flood Management schemes and thereby attract future funding not directly related to food production. By managing grazing levels, restoring water tables and joining up rush pasture fragments it should be possible to at offset some of the impacts of climate change.

Key adaptation recommendations for wet grassland and rush pasture:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Ensure appropriate levels of grazing are maintained.
- Increase connectedness, size and condition of rush pasture through habitat creation and restoration of adjoining semi-improved grasslands.
- Retain wetness by blocking artificial drainage.
- Re-introduce Sphagnum to sites where purple-moor grass has invaded blanket bog.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- On sites of importance for breeding waders where it is not viable to maintain water levels across the whole site, consider minor channelling of the water resource to retain some wet flushes.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Increase the variation in vegetation structure across site to maximize biodiversity. Rush management should be planned with the needs of different species in mind.
- If it is not possible to maintain wetness of rush pasture accept that it will change and facilitate conversion to other priority habitats such as species rich meadow.

Adapt land use for future conditions

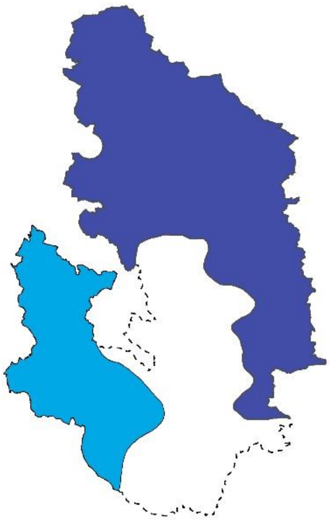
These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Flexibility in grazing is key – changing timings and providing alternative land for years where areas are flooded could be important to limit land abandonment on economically marginal land.
- Altering livestock may have benefits for the pasture habitats. Native grazer analogues such as appropriate cattle breeds that are less selective than sheep are more likely to facilitate a diverse sward.

Wet heath

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature assessed:

- Wet heath

Special quality:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Wet heath is an uncommon habitat in the PDNP, occurring on acidic and waterlogged peat soils in patches throughout heathland. Like other heath habitats (such as heather moorland), it is characterised by a greater than 25% cover of dwarf shrubs. It is distinguished from other heath habitats by a higher water table or otherwise waterlogged soil and a greater abundance of wet ground plant species. Cross-leaved heath is usually found here, as well as a greater abundance of *Sphagnum* mosses and common cotton-grass.

Wet heath habitat in good condition is quite similar to active blanket bog. Wet heath generally has shallower peat and is less rich in some characteristic blanket bog species such as hare's tail cotton grass. Blanket bog is assessed separately.

There are approximately 550 hectares of wet heath priority habitat mapped in the PDNP, but as this occurs in patches throughout heathland and heath type is not always specified, this may be an underestimation. This is a fairly fragmented habitat type, but is continuous with other heathland habitats and so likely has reasonable connectivity through the large area of heathland in the Dark Peak and South West Peak.

Wet heath is more species rich than other heathland habitats, and provides a refuge for blanket bog species that otherwise may be lost in some areas of the PDNP, and represents an intermediate stage between areas of dry heath and blanket bog. Rarer species within the PDNP such as round leaved sundew and bog cranberry can be found in wet heaths and have the potential to spread into more over time.

How vulnerable is wet heath?

Wet heath in the PDNP has been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with poorly documented current condition, and moderate adaptive capacity.

As wet heath depends on waterlogged soils, drying out of some sites represents the greatest risk, with potential reduction of *Sphagnum* cover adding to the problem. Despite being fragmented, wet heath grades into similar habitat types and so has reasonable connectivity. Organisational and financial support for moorland rewetting will benefit wet heath and counter some of the effects of climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The current condition of wet heath habitats in the PDNP is not well known as it is probably an under-recorded habitat. It is likely that it is in a similar condition to other heath habitats and subject to the same pressures. There are no Site of Special Scientific Interest (SSSI) units designated for wet heath, but most wet heath in the PDNP will be covered by the Dark Peak, Eastern Moors, Goyt Valley, and Leek Moors SSSIs, as well as the South Pennines Special Area of Conservation (SAC).

Due to historical contamination from industrial pollution in the PDNP, wet heath is likely to occur on heavily polluted peat. It is more at risk than other heath types due to its wetter nature, as heavy metals will be brought into solution by acidic water. Bare ground and increased nutrient levels have also allowed generalists such as rosebay willowherb to colonise in some areas. Nitrogen deposition is especially damaging, allowing vascular plants to outcompete and exclude *Sphagnum* mosses and increasing the susceptibility of heather to heather beetle. Heather beetle is a persistent presence and affects some areas, attacking mainly common heather and cross-leaved heath to a lesser extent.

Large areas of heathland are still managed for grouse or sheep production. Overgrazing and excessive burning is a threat to wet heath habitat due to removal of vegetation and exposure of bare peat facilitating erosion. The drainage associated with these land uses is also a threat to wet heath as waterlogged conditions are required to maintain the habitat. Historical drainage has likely converted much wet heath into other heathland such as heather moorland. However, without management of some kind, wet heath would naturally succeed into scrubland over time.

Damage associated with high visitor numbers is possible, but likely less than other heathland types. The scattered and wetter nature of wet heath means that high footfall and especially vehicle damage is unlikely due to the difficulty of the terrain, and so risk of erosion is lower. Wildfire damage will still affect some areas but will be lessened by wetter ground and less heather dominance.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

As a waterlogged environment, in which evapotranspiration and precipitation must be balanced, the greatest risks to wet heath habitats are related to changes in hydrological conditions. Loss of key species and replacement by drier heath species is also a key concern, as well as changes in management and human behaviour.

Direct impacts of climate change

Drier summer conditions are likely to be damaging for wet heath communities. A greater frequency and severity of summer droughts will be devastating for some areas. Wet ground species will be disadvantaged during the dry summer months, and may be replaced by more drought tolerant species. Cross-leaved heath is especially sensitive as it requires permanently wet conditions. As a result, this key species could be lost and replaced with common heather or other dwarf shrubs. Wet heath found outside peat areas may be at greater risk, as waterlogged conditions may be maintained by podzol formed iron pans, which are much more susceptible to drying due to their shallow nature. **[H]**

Increased winter rainfall may cause higher levels of nitrogen deposition on wet heaths. *Sphagnum* mosses' nitrogen uptake advantage over vascular plants is lost with increased nitrogen availability, and so they may be outcompeted and lost from some areas. **[H]** Increased nitrogen levels reduce *Sphagnum* production of polyphenol, a key chemical preventing decomposition in peat, meaning peat degradation may increase. **[H]** Nitrogen deposition also affects dwarf shrub species: Both heather and cross-leaved heath are sensitive to nitrogen deposition, which causes greater sensitivity to drought, frost, and heather beetle outbreaks. **[H]**

Compounding the reduced *Sphagnum* and dwarf shrub growth, more competitive grass species will have increased growth in higher nitrogen conditions, allowing species such as purple moor-grass to colonise and dominate. **[H]** These grass species will also have the advantage of a longer growing season due to rising temperatures, allowing them to outcompete other plant species, causing the species composition to move towards a lowland heath or acid grassland assemblage. **[H]**

Other indirect climate change impacts

More 'sunny' days during summer leading to higher light conditions can cause photoinhibition in sphagnum mosses, reducing their extent and limiting peat formation. As *Sphagnum* mosses are a key species for water retention, this could exacerbate the drying out of some sites. **[H]**

Drier summer conditions will likely also increase the risk of wildfire on moorland. Drought can cause even wet heath vegetation to dry out and become susceptible to ignition accidentally, from arson, or through managed burns running out of control at other times of year. Fires cause loss of vegetation as well as opening up bare ground to erosion and peat loss. **[H]** Aggressive colonisers such as purple moor-grass may also move in, changing the community composition and reducing species richness. **[H]**

Human behaviour change

Greater visitor numbers due to hot dry summers could be a threat to wet heaths, causing trampling of vegetation and increased path erosion, which may cause damage to wet heath habitats. However this effect may be partially mitigated by the less accessible nature and scarcity of wet heath. Wildfire risk may also increase with greater visitor numbers during hot, dry summers, though due to the waterlogged nature of wet heath the risk will potentially be less for these areas than for drier heather dominated moorlands. **[H]**

Wet heath is also susceptible to changes in management. Drying out of some sites due to climate change may make wet heath areas more desirable for grazing. Intensive management such as burning and high stocking levels would have a severe negative impact on wet heath habitats, pushing the community composition toward that of heather moorland or acid grassland **[L]**. Intensification of grazing can also lead to erosion and nutrient loading, having negative effects on dwarf shrubs and *Sphagnum* mosses. **[M]**

Invasive or other species interactions

Due to higher annual average temperatures, heather beetle and other pest species may increase in number and range. Both heather and cross-leaved heath are affected by heather beetle, and so may be stunted or removed from some areas, and be replaced by other species such as purple moor grass. **[H]**

Sedimentation or erosion

Increase in winter rainfall, especially as storm events, could be damaging for wet heath. Heavy rain and severe winds may damage plants, and increased runoff can cause soil erosion. As wet heath is generally found on thin peat soils, such erosion can lead to root damage, which in turn increases susceptibility of dwarf shrubs to winter desiccation, meaning community composition may be altered. **[H]**

Nutrient changes or environmental contamination

Changes in rainfall patterns may also affect nutrient cycles. Increased winter rainfall may cause flushing of nutrients from waterlogged environments, intensifying the already nutrient poor conditions. Conversely, increased precipitation is likely to increase nitrogen deposition. Summer droughts may also cause an increase in concentration of nutrients due to lower water tables. **[L]** Nutrient availability changes could impact the community composition of wet heath.

What is the adaptive capacity of wet heath? ***[Overall adaptive capacity rating: MODERATE]***

Resources are available for the management and restoration of heathland (including wet heath) through multiple sources. Environmental Stewardship options are available to individual landowners that have an interest in conserving their land. **[H]** There are also currently many organisations operating in the PDNP that can conduct or facilitate works to increase the resilience of heathland e.g. Moors for the Future Partnership, Eastern Moors Partnership, The National Trust and RSPB. Moorland rewetting is a stated aim of many of these organisations, which could increase the area and resilience of wet heath. **[H]** However, although management can be taken to partially offset the effects of climate change, there is limited agreement about future land use due to conflicting interests of different stakeholders; the aims of conservation organisations potentially conflict with those managing their land for sheep farming or grouse shooting. **[M]**

The exact extent of wet heath is unknown, but it is a fragmented habitat with low connectivity across the landscape. It does, however, grade into other heathland types and blanket bog, so there is some potential connectivity for most species. Long distance seed dispersal is a barrier to the spread of wet heath, meaning some wet heath species will struggle to naturally colonise suitable ground if it is available. **[L]**

Wet heath species can be vulnerable to changing conditions due to their water requirements; diverse communities will be more resilient than those dominated by one or two species. Multiple plant species will take up more available water during times of water stress, and some plant species play a vital role in the response of below-ground biotic processes. **[L]** The loss of cross-leaved heath due to drier conditions would be difficult to recover from, but it may be replaced by other dwarf shrubs. Wet heath in good condition is afforded some protection from invasion by species such as bracken by nature of its being waterlogged. **[H]** Wet heath in mosaic with other heathland and scrubland may be more adaptable. **[L]**

Key adaptation recommendations for wet heath:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Updated habitat mapping taking into account peat depth is needed to determine exact size and extent of current wet heath resource.
- Moorland rewetting work should be continued as a top priority.
- Identify sites that can act as climate change refugia due to their favourable topography, aspect, hydrology, or good species diversity, and manage these sensitively.
- Minimise erosion through management of access, appropriate grazing levels, and reduction of burning.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change

- Strengthen footpaths and manage increased visitor access to minimise disturbance in key areas.
- Careful livestock management at high risk sites.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Structural diversity within heathland vegetation should be increased - including wet heath patches, diverse age classes of dwarf shrubs, and scattered trees and scrub to provide refugia for sensitive plants and invertebrates.

Accept that habitats need to be dynamic and not fixed. Consider that designated site boundaries may need to change as habitats move/change to create larger functional sites, and features of interest may change. Liaise with other protected landscapes to share knowledge and management techniques, and contribute to the national picture.**Adapt land use for future conditions**

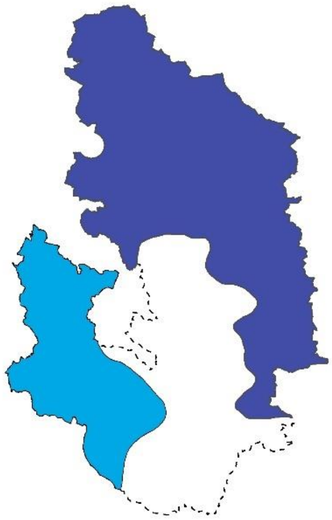
These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Create future conservation objectives in the knowledge that wet heath and other habitat types will move along a continuum, and so the ideal location to target actions for particular species will change with the climate.

Wet woodland

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature(s) assessed:

- Wet woodland

Special qualities:

- Internationally important and locally distinctive wildlife and habitats
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

Wet woodland occurs on permanently wet or seasonally wet soils and is usually dominated by alder, birch and willow trees. Wet woodlands are found on floodplains, flushed slopes, valley sides, cloughs, and along stream edges. It also occurs as a mosaic within other habitats including dry woodlands, bogs and fens, for example as willow scrub on moorland.

In the PDNP wet woodland is most common in the Dark Peak and South West Peak, with approximately 90 hectares of priority habitat mapped. However, it is likely that more is unrecorded and within mosaics of other habitats. Nevertheless, the total is one of the smallest for any habitat in the PDNP and wet woodland is therefore a very rare habitat.

This habitat is important as it provides cover and breeding sites for a wide range of species that are not commonly found elsewhere, particularly dead wood invertebrates, ground flora such as kingcup and greater tussock sedge (also found in open rush pasture), birds such as willow tit (a rare and declining species on the UK Red List), and mammals including otter.

How vulnerable is wet woodland?

Wet woodland in the PDNP has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor, highly fragmented current condition, and a moderate adaptive capacity.

Wet woodlands in the PDNP are already highly fragmented, but many of the remaining patches are in good condition. Wet woodlands with low tree species diversity are likely to more vulnerable than those that are more diverse. The area of wet woodland in the PDNP may be reduced by climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

As with the rest of the UK, large tracts of the PDNP's wet woodland have been lost through land use changes. Land clearance and drainage for agriculture and forestry has reduced wet woodland extent to a highly fragmented version of its former range. Overgrazing has also been detrimental as it prevents ground flora and sapling establishment. Surviving wet woodland occurs on the margins of other habitats, such as mosaics on Ramsley Moor and Warslow Moors, and on floodplains like the River Derwent where the land has not been reclaimed for agriculture. This is mostly in good condition. Abandoned sites such as disused railway lines and extraction sites have developed into new patches of wet woodland in recent years, for example at Rowsley Sidings. Ongoing land use changes are a risk factor, particularly within mosaic habitats.

Many wet woodlands in the PDNP occur on flushed slopes and near watercourses. This means they are easily affected by agricultural run-off, in the form of water pollution and nutrient enrichment. In some areas mismanagement of water levels is resulting in scrub invasion, while other wet woodlands are particularly at risk from invasive or nuisance species due to their close proximity to waterways. Himalayan balsam is a common problem as the seeds spread quickly allowing it to take over the woodland understory, which then prevents seedlings and woodland ground flora from establishing.

Sensitive management of riverside trees and wet woodlands has begun in parts of the PDNP, as its role in flood alleviation is increasingly being recognised. Although likely undervalued compared to bogs and marshes, wet woodlands help stabilise slopes and banks and are able to absorb large amounts of water as rivers and streams overflow. Land management practices continue to influence the state of the PDNP wet woodlands. Removal of old trees removes fungi, mosses and other flora and fauna from a site. Work is being carried out by local Wildlife Trusts, Trent Rivers Trust and others. The very small extent of wet woodland remaining in the PDNP will require careful management to prevent further degradation.

What are the potential impacts of climate change? *[Overall potential impact rating: HIGH]*

Direct impacts of climate change

Climate change has the potential to have a severe negative impact on the PDNP's wet woodland, both directly and indirectly. The habitat is restricted to areas with wet soils, predominantly on slopes and near waterways. Rainfall is a limiting factor that has the potential to greatly alter the distribution of wet woodland as it becomes more variable.

Wet woodland tree species are very sensitive to the direct effects of changed precipitation levels – predicted to occur through wetter winters and drier summers. Waterlogging and drought are likely to lead to a change in community composition and habitat structure, along with a reduction in species productivity. Waterlogging in low lying areas could increase the dominance of some tree species such as alder and willow, while drier soils on slopes could see the loss of these species and will likely convert to dry woodland. Many remaining areas of wet woodland are dependent on water input from springs and seepages. Changes in precipitation may lead to these drying out and seasonal or permanent disappearance, with significant loss of associated wet woodland flora and invertebrate fauna. In some cases the habitat may again be lost to drier woodland. **[H]**

The increased mean temperatures and fewer frost events that are expected with warmer winters are likely to cause changes in the growing season of plants. Already seen in some species, trees will likely have earlier bud burst, putting them at an increased risk of frost or cold damage. Other trees may have reduced winter chilling and incomplete winter hardening leading to reduced seed germination in some species. Warmer temperatures combined with reduced rainfall may leave boreal and sub-boreal bryophyte and moss species susceptible to drying which could lead to species losses in some areas. **[H]**

Storm events may kill older trees which are an essential part of healthy wet woodland Gaps may be replaced by scrubby stands **[H]**. Erosion of river banks may reduce bankside tree cover, changing otter habitat, impacting on water temperature regimes, reducing diversity of river habitat, and reducing overall woodland size. **[M]** Habitat structure and community composition may change as non-native invasive species such as Himalayan balsam continue to spread. **[M]** Nutrient levels could also be impacted by concentration or flushing. **[L]**

Human behaviour change

While many wet woodlands have already been degraded by land use changes, they remain sensitive to future changes in farming and forestry pressures. As some wet woodlands dry out they may become more suitable for grazing or forestry, putting the habitat at risk. Increases in water abstraction during dry periods will exacerbate the direct effects of climate change, creating drier areas and limiting potential for expansion. **[L]**

With hotter, drier summers predicted, it is likely the PDNP will see increased visitor numbers, with growing numbers near waterways and woodlands. This poses a risk for ground flora that can be easily trampled if people leave designated paths. Rank species such as nettles and thistles could increase and other ground flora may be impacted. Higher visitor numbers will also cause an increased disturbance to wildlife potentially resulting in the loss of breeding habitat for birds and otters. **[L]** Conversely, the increased interest in this habitat as a flood, erosion and water quality management tool could create opportunities for wet woodland restoration, expansion or further creation. Wet woodland found or created along river valleys will be especially useful in natural flood management and slowing the flow of water. **[M]**

Invasive or other species interactions

Warmer winters are also likely to lead to the increased survival and prevalence plant diseases such as *Phytophthora*. Alder is one of the wet woodland tree species that is commonly affected by *Phytophthora*. Damage and death of these trees along with others affected by disease will change the community composition and could affect the overall health of the woodland. **[H]**

Other indirect climate change impacts

Drier woodlands with reduced humidity would likely cause a decline in species requiring damp habitats including crane flies and other invertebrates in the wet woodland assemblage. This in turn would reduce the availability of food for birds and their young, which may lead to a decline in some woodland birds. Wet woodland specialists such as the rare marsh tit will be at greater risk. Changes to soil moisture levels could also facilitate the invasion of drought tolerant species. **[M]**

What is the adaptive capacity of wet woodland? ***[Overall adaptive capacity rating: MODERATE]***

Despite wet woodland being a highly fragmented habitat type in the PDNP with strict hydrological requirements, the dominant tree species are widespread and a range of management and restoration options are available, giving this habitat a moderate adaptive capacity within the PDNP.

Wet woodlands are often small and highly fragmented across the landscape. **[H]** The poor connectivity between sites is detrimental to both the flora and fauna found within them. Tree species and ground flora have limited dispersal ability, particularly as habitat location is limited by water availability and soil moisture. **[H]** However, many of the dominant tree species present in wet woodlands are expected to be relatively resilient to climate change. **[M]** Some birds and mammals that utilise wet woodlands may be able to disperse, or find similar habitat traits in dry woodlands, providing resilience. However, species with a poor dispersal ability are likely to suffer. The willow tit for example, already scarce, may be vulnerable to extinction in the PDNP. Ground flora and invertebrate communities may be most at risk as their dispersal range is more limited and they are more likely to depend on high humidity and high soil moisture levels. **[M]**

Tree diversity is an important factor in climate change resilience. Wet woodlands with low tree diversity have a greatly reduced capacity to adapt. Should a species-specific tree disease outbreak occur (for example *Phytophthora* in alder trees), the whole woodland may be lost quite rapidly. With an increased diversity of tree species the woodland has a much greater resilience. As wet woodlands occur on a range of soil types (both nutrient-rich mineral soils and nutrient-poor organic soils), their greatest limiting factor is soil moisture and the availability of other tree species to regenerate. **[M]**

Some environmental stewardship options are available for maintenance and/or restoration of wet woodland within farmed landscapes. **[H]** Good availability of financial resources and information means that management organisations may be able to facilitate works to increase the resilience of wet woodland in the PDNP. **[H]** Policy or management actions may be undertaken to partially overcome or offset climate change stressors, by promoting structural and species diversity within existing wet woodlands and managing water availability across catchments. **[M]**

Key adaptation recommendations for wet woodland:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Map existing wet woodland habitat to assess value and content.
- Continue with sensitive woodland management.
- Continue with work on managing invasive species such as Himalayan balsam.
- Continue management of woodland along watercourses to reduce flood risk.
- Evaluate whether the introduction of beavers would be a feasible and appropriate method of delivering ecosystem service benefits such as flood mitigation, water quality and wet woodland creation.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Identify sites for wet woodland restoration, expansion and/or creation. Care should be taken to ensure this is not at the expense of other wetland habitats that are of value. Some sites could just be scattered trees, others more dense woodland and wet scrub – smaller willows of various locally native types.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Establish trees and encourage natural regeneration to increase species diversity, structural diversity, and patch size.
- Evaluate whether there are benefits in establishing scrub to stabilise eroding edges of blanket peat, and implement if appropriate.

Adaptations that could aid other features

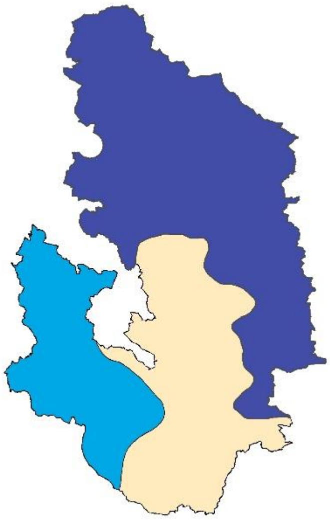
These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Increase woodland cover – to keep waterways cool and to provide shelter for other species as temperatures increase.
- Increase connectivity between woodlands to provide wildlife corridors.

Woodlands

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature(s) assessed:

- Woodlands and scrub
- Veteran trees, wood pasture, hedgerows

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology
- Internationally important and locally distinctive wildlife and habitats
- Undeveloped places of tranquillity and dark night skies within reach of millions
- An inspiring space for escape, adventure, discovery and quiet reflection
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

Woodlands occur on a range of soils, producing different types defined by their dominating species and growth patterns. The five main types of woodland found in PDNP are 1) upland mixed ash woods, 2) upland oak/birch woods, 3) veteran trees, wood pasture and parkland, 4) plantations which are conifer, broadleaved, and mixed, 5) scrub and hedges. Areas of ancient woodlands often have a more mixed species composition where they are found in the PDNP, and so may not fit exactly into these categories. Smaller patches of woodland, such as shelterbelts, in-field and boundary trees, are also found throughout the PNDP. Wet woodland is present but this is discussed separately.

The PDNP is poorly wooded compared to the UK and European averages with varying levels of fragmentation. Approximately 5,000 hectares of woodland has been mapped in the PDNP, 3,500 ha of this being priority habitat. An additional 10,500 ha of scrub has also been mapped, largely as non-priority habitat. 60 ha of mapped woodland is ancient woodland or plantation on ancient woodland sites. Ancient woodlands are a refuge for biodiversity, containing many species that require long established woodland. As a result, ancient woodlands are a valuable resource that are not easily replaced. Plantations on ancient woodlands, often coniferous rather than native broadleaf, still harbour many of these ancient woodland indicator species and have the potential for high biodiversity if restored.

Some woodland habitats are nationally and internationally important for their flora and fauna. Ash woods in the dales and oak woods in the Dark Peak and South West Peak are both Special Areas of Conservation (SAC) features. Upland mixed ash woods are listed as a priority habitat under Annex 1 of the European Union Habitats Directive (as *Tilio-Acerion* ravine forests). They are rich habitats for wildlife with many nationally important species such as small and large-leaved lime, lily-of-the-valley, white-spotted pinion moth, and lemon slug. At the south-eastern edge of their range in Britain, upland oak/birch woods, also an EU Habitats Directive priority habitat, support a range of irreplaceable ancient woodland species. The ground flora here includes yellow archangel, dog's mercury and wood anemone, along with upland birds like pied flycatcher and wood warbler, and invertebrates such as northern wood ant, ash-grey slug and the purple hairstreak butterfly.

Less extensive and non-native woodland types are also important for biodiversity, often as part of a wider landscape mosaic. Plantations can provide habitat for bird species such as crossbill and nightjar in felled areas. Veteran trees are important for rare invertebrates, lichens, fungi, bats and breeding birds. Parklands with veteran trees are also of national importance; For example, Chatsworth Old Park is a Site of Special Scientific Interest (SSSI).

Scrub and hedges are valuable feeding habitat for birds, particularly in winter when they provide berries for species such as fieldfares and redwings. All woodland types host a variety of fungi, ferns, mosses, liverworts, and lichens. The historic nature of ancient woodland sites means they can also hold important archaeological records such as charcoal pits.

How vulnerable are woodlands?

Woodlands in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor fragmented current condition, and a moderate adaptive capacity.

Woodland condition in the PDNP is variable, with smaller patches generally in poor condition, but larger areas under SSSI protection faring better. Smaller woodlands with low tree species diversity are likely to be more vulnerable than those that are larger and more diverse. The area of woodland in the PDNP may be reduced by climate change, especially single species woodlands, though the demand for climate change mitigation may encourage new woodland creation.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Woodlands in the PDNP have varying levels of protection. Many woodlands in the White Peak are designated within SSSIs. Other woodlands, outside designated sites, in the Dark Peak, White Peak and South West Peak are managed or part-managed by National Trust, Natural England, estates, and local Wildlife Trusts. Veteran trees, wood pasture and larger patches of ancient woodlands are generally protected through designation or management plans. Individual trees can also be protected through Tree Protection Orders. However those trees and woodlands outside SSSI sites and conservation ownership are left with no protection.

Larger native mixed ash woodlands in the White Peak are mostly in good condition although they are threatened by the presence of ash dieback. Symptoms of this disease are now showing throughout the PDNP and it is predicted to kill 60-90% of ash trees across the UK. Ravine woodlands with low diversity are especially vulnerable. The National Trust is currently removing infected ash trees that present a health and safety risk to the public at Dovedale and, along with Natural England, are increasing tree and shrub diversity in patches in Dale ash woodlands. Chatsworth Estate is also undertaking similar management measures. Increasing species diversity is an opportunity presented by ash dieback to make woodlands more resilient and biodiverse. It is of particular priority in areas where woodlands are currently ash dominated, and Natural England are progressing this work at Lathkill Dale.

Smaller fragmented woodlands across the PDNP are generally in poor condition. Many of these woodlands are lacking in species diversity due to past and present anthropogenic and browsing pressures – in particular, overgrazing by deer and sheep prevents regeneration of trees and ground flora. The structure and diversity of many woods has also been altered by Dutch elm disease over the last 50 years, impacting a range of species including the white-letter hairstreak butterfly which has lost much of its food source.

Invasive species are present in PDNP woodlands. Rhododendron in particular shades out the understorey and outcompetes many important species that contribute to the diversity and conservation value of the woodland. Non-native sycamore and beech regeneration is colonising some woodlands. However, these trees may become more desirable as fast growing replacements for ash trees lost to dieback, though this would be as part of a diverse mix with true natives such as lime, alder, and field maple.

Management of woodland sites has changed dramatically over the last few centuries. Traditional management techniques and practices such as coppicing and pollarding have largely ceased and some sites have been neglected. As a result the woodland structure has been completely altered. Some woodlands have very few veteran trees and deadwood left, which is now being addressed in some areas. Development such as housing and quarrying, and tourism have also altered sites due to the increase in disturbance and pollution. Lichen and bryophyte communities are strongly affected by air pollution in particular. Sulphur dioxide pollution has been dramatically reduced in recent decades allowing some of these species to recover. There are unknown impacts on woodlands from the use of agro-chemicals. These are potentially affecting important tree mycorrhizal relationships.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Invasive or other species interactions

Climate change has the potential to have a severe negative impact on PDNP woodland, both directly and indirectly. Woodlands are very sensitive to changes in precipitation and temperature that can not only stress the dominant tree species but also makes them more susceptible to disease and invasive species. As plant diseases (such as *Phytophthora* and ash dieback) become more prevalent they pose the biggest risk to the long-term health and diversity of woodlands. Key canopy species may be lost or severely reduced through both disease and extreme weather events, increasing the exposure of ground flora and potentially its vulnerability to drought and invasive species. Vernal ground flora such as wild garlic and bluebells are likely to be less at risk due to their shorter exposure period. **[H]**

Flood events, predicted to increase with wetter winters, will facilitate the spread of invasive or nuisance plant species such as Himalayan balsam that threaten the understorey, with woodland near waterways most susceptible to invasion. **[H]** Increased atmospheric carbon dioxide and nitrogen may increase plant growth rates allowing competitive species such as rhododendron to spread in the understorey. How much the community structure will change is unknown as all woodland species will likely experience faster growth. **[L]** Animals such as insects, deer, and grey squirrel are also a potential threat to stressed woodlands. Browsing of seeds and seedlings in particular may put some tree species at risk as they become unable to regenerate. Oak may be at an increased risk of decline from the wood boring beetle, the two spotted oak buprestid. It is possible that new pests and diseases may spread from the south.

Direct impacts of climate change

Changes in temperature and precipitation that alter seasonal weather patterns could have a large impact on woodlands. Warmer winter temperatures could lead to: reduced vernalisation of fruit affecting seed viability, inadequate winter hardening leaving plants vulnerable to cold snaps, and advanced bud burst as warmer days arrive earlier. The species composition of woodlands may be altered especially where natural regeneration is reduced. There may also be a loss of mosses and bryophytes in some areas that have both warmer temperatures and reduced rainfall, followed by a shift in species to those that are better adapted to the conditions. Ash woods and oak woods on the edge of their range are particularly sensitive to a climate shift. Northern ash wood types with assemblages more similar to National Vegetation Community (NVC) W9 may become move towards south eastern W8 assemblages. The rare NVC W8g wood sage sub-community may be vulnerable to species composition changes. Characteristic PDNP oak wood communities with moss and lichen rich bilberry understories (NVC W16b) may be lost as they are replaced by assemblages more common in the south of England (more similar to NVC W16a) **[H]**

Water table fluctuations, flooding, and drought all have an impact on plant root depth and distribution of species. Waterlogging is likely to restrict tree root depth for some species - leaving them more exposed to wind throw and drought. The stability of soils with long-term waterlogging may also be compromised. Periods of drought could affect plants with shallower roots, those on free-draining soils, and drought-sensitive tree species such as beech. In years of extreme drought tree mortality may be widespread leaving the woodland ground flora at greater risk too. As soil moisture profiles are altered there will likely be a shift in community composition that could convert dry woodlands into wet woodlands or vice versa. **[H]**

Extreme events such as an increased frequency of wind throw and environmental stress are a threat for woodland plants, especially mature and veteran trees. Loss of older trees will also cause a loss of whole communities associated with them – specialist species such as fungi, lichen, and invertebrates. Conversely, some of these species may survive in deadwood or deadwood will act as a new habitat for other species to thrive in. Gaps in woodlands may be filled by pioneer tree species such as birch or rowan that could become more dominant in some areas. Such gaps, together with the impact of temperature rise, may also provide opportunities for colonisation by southerly insects such as silver-washed fritillary. **[H]**

The growth rate of trees can be influenced by the carbon dioxide concentration in the atmosphere. With a predicted rise in carbon dioxide it is possible trees may experience increased productivity. Seedlings may grow quicker and leaf area could also increase. This will enhance natural regeneration and improve canopy resistance. However, woodlands with relatively open canopies could become more shaded, causing changes to the ground flora and possibly altering community composition. **[L]**

Human behaviour change

Increased visitor numbers are expected in the PDNP, particularly in woodlands as people seek cooler places to walk on hot days. Bare ground may result where insufficient light is available through the canopy, or ruderal species such as nettles, thistles and other rank species may colonise in more open areas. This is also likely to impact animals, with disturbance causing changes to breeding and feeding patterns for birds and invertebrates. **[H]**

Woodland creation and tree planting are likely to increase as part of climate change mitigation efforts. It is a popular carbon sequestration method that may benefit PDNP woodlands as their area of cover and connectivity can be enlarged and improved. **[M]**

Nutrient changes or environmental contamination

Woodland plants are sensitive to changes in nutrient availability, both in the air and on the ground. Lichen and bryophyte communities are especially sensitive. Nitrogen deposition, a result of air pollution, can be particularly damaging. **[M]** Agricultural changes on adjacent land may also alter nutrient inputs which influence community composition and habitat structure. Ground flora is likely to be more affected than trees. **[L]**

Other indirect climate change impacts

Hotter, drier summers are predicted to lead to an increased incidence of wildfire. Woodland flora and fauna are susceptible to damage and habitat loss. Broadleaved trees such as oak are highly resistant, but conifers, ground flora, and woodland understorey are more at risk. Conifer plantations next to moorland are the most at risk due to the level of dryness they could reach in summer when fire risks are highest and spread from moorland fires. The character and composition of woodlands may be altered as regeneration patterns change. This may also cause a loss of nesting and feeding habitat in some areas. **[M]**

What is the adaptive capacity of woodlands? ***[Overall adaptive capacity rating: MODERATE]***

While woodlands are a fragmented habitat type across the PDNP, the dominant tree species have a wide biogeographic range and there are a variety of management and restoration options available giving this habitat a moderate adaptive capacity within the PDNP.

In the Dark Peak and South West Peak, woodlands are largely confined to cloughs and gullies, while in the White Peak they are mostly confined to the dales. Under current land management regimes there is limited expansion potential into neighbouring areas. Adjoining land is often managed for sheep or grouse, or is valued for its own conservation characteristics. Due to spatial limitations, there are severe impediments to feature persistence and dispersal. Connectivity is variable and in areas that are highly fragmented the high edge to surface ratio increases woodland vulnerability to agricultural intensification. However, with increasing interest in increasing woodland and tree cover to benefit carbon storage, water quality, flood risk and biodiversity, there may be increased opportunities for some native woodland expansion beyond the existing cloughs, slopes, and dale brows. **[H]**

Diverse mixed species woodlands have greater resistance to climate change stressors than single species woodlands. This is especially true with regards to disease or pest outbreaks that only affect one or two species such as ash or oak. Larger stands of woodland are also more resilient as they are able to maintain a cooler microclimate and have more stability in high winds. Deeper roots offer extra support in storm events and help stabilise soils that can otherwise be eroded by heavy rainfall. Wooded slopes help reduce flood risk for lower lying landscapes and in riparian areas can keep waterways cool which benefits fish and invertebrate populations. Areas such as the White Peak dales have been highlighted as climate refugia – where cooler woodlands provide shelter for other species within the landscape allowing them to persist longer in the changing climate. **[H]**

Some environmental stewardship options are available for maintenance, restoration and creation of woodland. Where woodlands are on private land these schemes provide incentive for keeping woodlands in good condition. Most upland ash woods (84%) are protected within SSSI sites, as are many of the upland oak/birch woodlands. Good availability of financial resources and information means that management organisations are able to facilitate works to increase the resilience of woodland in the PDNP. One example is Moors for the Future Partnership and National Trust's work on clough woodlands in the Dark Peak where the planting of a mixture of native trees is taking place. **[H]** Policy or management actions may be undertaken to partially overcome or offset climate change stressors, by promoting structural and species diversity within existing woodlands and managing water across catchments. **[M]**

Key adaptation recommendations for woodlands:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Reduce grazing pressures where possible. Recognise the importance of an integrated deer management plan for the park.
- Encourage more continuous cover forestry – to maintain higher levels of carbon storage and decrease soil losses.
- Improve protection, management and recruitment of veteran trees.
- Consider water management in woodlands predicted to experience drought.
- Further study is required to explore appropriate opportunities for woodlands to be used in local wood fuel schemes.
- If visitor numbers increase at easy to access locations, encourage visitors to use alternative transport such as bikes and public transport to maintain tranquillity of the area.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Increase diversity of tree species; especially in single species woodlands. Accept change in composition of woodlands, such as accepting species not previously native to the PDNP.
- Continue improving woodland condition – more native woodland creation, encourage regeneration to increase structural diversity, increase patch size (>2ha) to meet habitat requirements for birds and other species, increase decaying wood for replenishing soils.
- Natural woodland regeneration by excluding stock should be seen as preferable to tree establishment, with the latter principally to increase diversity - importance of scrub is underestimated.
- Convert small or unused conifer plantations to broadleaf/mixed woodlands.
- Increase establishment of field and boundary trees, particularly across the White Peak, to increase habitat diversity and connectivity, replace trees lost to Ash Dieback, enhance the landscape and provide shade and better grazing for livestock in hotter summer conditions.

Adaptations that could aid other features

These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Increase connectivity between woodlands to provide wildlife corridors.
- Increase woodland cover – to keep waterways cool, provide shelter for other species as temperatures increase, increase carbon storage, and improve water quality.

5.8. Watercourses, ponds and reservoirs

Watercourses, ponds and reservoirs

	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Dew ponds and other ponds	High	Low	**Very High**	258
Good water quality	High	Moderate	**High**	263
Reservoirs	High	Moderate	**High**	268
Reservoirs and water management features	High	Moderate	**High**	273
Rivers and streams	High	Moderate	**High**	278
Riverside meadows associated with meandering river channels	High	Low	**Very High**	285
Vanishing rivers	High	Moderate	**High**	290

Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for help understanding the feature assessments on the following pages.

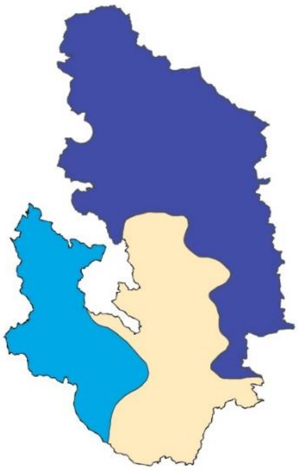
Dew ponds and other ponds

Overall vulnerability rating:

Very low	Low	Moderate	High	**Very High**

Feature(s) assessed:

- Dew ponds and other ponds



Special qualities:

- Internationally important and locally distinctive wildlife and habitats
- Landscapes that tell a story of thousands of years of people, farming and industry

Feature description:

This feature is predominately found in the White Peak, but can also be found in much smaller numbers in both the Dark Peak and South West Peak. There has been a significant loss of ponds in the PDNP and across the UK. The White Peak has the majority of the remaining ponds, the Dark Peak having significantly fewer and the South West Peak least of all.

Dew ponds are human-made and were usually created to help provide water for livestock. In the White Peak many of the ponds were created in the 19th century and give an insight into farming in the area. These circular ponds were lined with lime and clay. Cobbles were often placed on the surface to create a durable surface. Many dew ponds were re-lined with concrete in the 20th century.

Other types of ponds included within this feature are those associated with mills and village ponds.

Within the PDNP 401 ponds are recorded as of being high value and classed as priority habitat, primarily due to the presence of priority amphibians – toad and great crested newt. Half of the world's population of great crested newts are found within the UK and ponds are a key habitat for this species. The network of dew ponds in the White Peak holds a nationally important population of great crested newts. Ponds also provide a habitat for aquatic invertebrates.

How vulnerable are dew ponds and other ponds?

Dew ponds and other ponds in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor current condition, and a low adaptive capacity.

Extreme events including flood and drought could have a significant impact on this feature, reducing their functionality and potentially leading to ponds being abandoned or infilled. Dew ponds with intact historic surfaces (clay and cobbles) are becoming increasingly rare. The adaptive capacity of this feature is low as there are a limited number that are functional. PDNPA funding is currently available for pond restoration, but this is very limited.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

Dew ponds and other ponds are viewed as vulnerable, particularly those found in the White Peak. Surveys suggest there was a significant reduction in their number, potentially up to 50%, in the 1970s and early 1980s. More recent studies have seen the number of ponds continue to decline but at a slower rate. In the South West Peak and Dark Peak the figures have remained relatively stable, however the information available on their current condition is limited. It is also not known how many new ponds have been created in gardens or schools.

There is a wide variation in the habitats provided by ponds which is due to the individual water quality, depth and chemistry having a significant impact on the plants it supports. The type of vegetation and its coverage in each pond helps to determine the range of aquatic invertebrates found. Populations of several nationally scarce water beetles and the great crested newt make this PDNP habitat even more important. Several locally rare plants such as common water-crowfoot, pond water-crowfoot and marsh cinquefoil can also be found at certain locations.

Changes in water quality have seen a negative impact on ponds. For example run-off from the surrounding areas can cause fertiliser, slurry and herbicides issues in ponds. If the levels of nutrients and minerals increase it can lead to an excessive growth of algae reducing the amount of oxygen found in the water, impacting the habitat considerably.

Intensive management of farmland that surrounds dew ponds can also damage ponds lined with clay if trampled by heavy livestock. Management can also alter the surrounding habitats which some pond species rely on.

The dew ponds of the White Peak have been particularly vulnerable to neglect, leading to infilling as well as abandonment when no longer needed. The clay or concrete linings can crack if not maintained which removes the functionality of the pond. In addition, the re-lining of dew ponds with concrete, whilst effective for water retention, can mask or destroy the historic pond lining, altering its character significantly.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Nutrient changes or environmental contamination

Increased levels of nitrogen and carbon dioxide could have a significant impact on the water quality and its chemistry, affecting the growth rates of pond vegetation. A rise in nutrients in water can lead to excessive growth of algae reducing the amount of oxygen and affecting invertebrates. Algal blooms could change the whole community structure and function of a pond. **[M]**

Higher average temperatures leading to longer growing seasons could also affect the balance of nutrients and plankton in pond ecosystems. This could affect a number of groups such as diatoms, desmids and zoo plankton, which could then affect macroinvertebrates and other species all the way up the food chain. It may be that phytoplankton blooms start earlier and last longer which would have knock-on effects through the food chain. There could be a decrease in light penetration because of increased phytoplankton, as well as competition for carbon dioxide and lower oxygen levels as phytoplankton decompose. These could all lead to a loss of fish and other animals. **[M]**

If the frequency of storms increases there could be increased run-off leading to eutrophication, impacting the ecosystem of the pond. Standing water is highly sensitive to changes in the amount of sediment and nutrients. **[M]** Any reduction in 'flushing' during drier summers may see concentrations of nutrients increase. If these changes cause a rise in algae growth it may be difficult for ponds to recover. Wetter winters may help to counteract the impacts of drier summers, but dew ponds are less dependent on this process as they usually don't overflow very much. **[L]**

A rise in atmospheric carbon dioxide could result in acidification of water through the dissolution of carbon dioxide which makes carbonic acid, although the impact should be reduced in ponds lined with concrete or limestone due to their high alkaline content. **[M]**

Human behaviour change

Ponds have already been damaged by livestock and this could worsen if grazing levels increase due to climate impacts. Changes in agricultural economics and increased availability of piped water could see ponds abandoned or infilled. **[M]**

Ponds are sensitive to changes in the surrounding area caused by droughts or floods. For example dew ponds may no longer be maintained in areas no longer suitable for livestock. Conversely natural ponds may benefit from increased shading if land is abandoned. **[M]**

Direct impacts of climate change

Increased average temperatures and longer growing seasons could result in lower dissolved oxygen levels in ponds. It may be that the interface between water and the sediment layer becomes deoxygenated although this effect may be limited to shallower ponds. **[M]**

If ponds dry up earlier in the year during drier summers, amphibians may not have time to complete their lifecycle. Phosphorous may be released from sediment due to the temperature dependency of nutrient-cycling rates in the sediment, increasing eutrophication risk. As a result, some invertebrates and fish may be unable to survive. **[M]**

Dew ponds, especially those located on hill tops, rely entirely on rainfall and run-off from a small surrounding catchment. Drier summers and drought could therefore have a significant impact. Long vegetation around the edge of a pond can impact evaporation rates, often decreasing it due to shading the water but sometimes increasing it. Drought may restrict vegetation growth, which would alter this interaction. **[M]**

An additional potential impact of drought is that stream-fed ponds may lose connection with other water bodies for part of the year. Ponds can dry out completely early in the year, losing their function as permanent ponds. Some pond species can adapt by moving to other ponds, or survive as eggs or in other life stages in mud. However, if multiple ponds dry out then species could potentially be lost. Dead vegetation from the pond drying out may add organic matter and nutrients, increasing the chances of infill. Extreme drought conditions could also crack pond linings. **[M]**

An increase in how often ponds dry out or see water levels drop, can stress plants and animals – making them unsuitable as habitats. PDNP dew ponds provide internationally important breeding grounds for the great crested newt, so any change could have a significant impact on numbers. As great crested newts only travel a limited distance from their birth ponds, landscape connectivity is very important. **[M]**

If clay-lined dew ponds are subject to greater extremes of temperature, or prolonged periods of dry weather, they could suffer from freeze/thaw action or cracking, reducing their water retaining capacity, and making them more likely to be re-lined with concrete. **[M]**

Invasive or other species interactions

A rise in average annual temperatures could see a further increase in non-native plants such as Australian swamp stonecrop or Canadian pondweed. If native species are outcompeted, the biodiversity of the pond may decrease affecting plant and animal communities. Submerged species may be replaced by floating or evergreen species. **[M]**

Sedimentation or erosion

Wetter winters leading to increased flooding could impact marginal vegetation, which can be sensitive to erosion. Flooding could affect the stability of banks and lead to an increase in nutrient levels within the pond. **[H]**

An increase in storm events could cause more sediment to reach ponds, as well as nutrients from run-off such as fertiliser applied to the surrounding land**. [L]**

What is the adaptive capacity of dew ponds and other ponds?

[Overall adaptive capacity rating: LOW]

There are many ponds within the PDNP however only a small number are functional as few have been maintained or restored. The ponds are well dispersed and a more resilient network could be created if more were restored. **[VH]**

Some of the important species associated with PDNP ponds, for example the great crested newt, have limited dispersal capacity. There are large distances of inhospitable habitat in between many ponds that can affect amphibians, particularly those that are less able to disperse. Pond invertebrates however seem to be better at dispersing than invertebrates in other habitats, as ponds have always been separated in the landscape. This increases the adaptive capacity of this aspect of ponds as a habitat. **[VH]**

Recovery of climate-affected ponds could be limited by species capabilities and dispersal. Some ponds may have dried out during hot summers or others lose nutrients or sediments from increased storm events. Some species can benefit from seasonal drying of ponds but this may not work if ponds dry out for longer periods. Species without these survival strategies for dry periods could have nowhere to go. The fragmented nature of the habitat means the potential for re-colonisation from other ponds is limited, so once these species are lost the ponds may not recover. **[M]**

PDNPA grants are available for pond restoration, but are very limited. It is not currently possible to implement adaptation for ponds under agri-environment schemes, as current agri-environment schemes do not fund restoration of man-made structures such as dew ponds. **[H]**

Many dew ponds are under the management of nature conservation organisations such as those within National Nature Reserves and County Wildlife Trust land. This may help to protect these dew ponds more than others in the PDNP. **[L]**

Key adaptation recommendations for dew ponds and other ponds:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Maintain and enhance existing sites, where possible, consider re-lining failing ponds with materials that reflect their historic character.
- Reduce non-climatic sources of harm such as non-native species and nutrient sources.
- Minimise agricultural inputs, especially slurry, fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.

- Manage biosecurity to limit spread of invasive and non-native species.
- Investigate external funding sources for a major pond project using citizen science.
- Create semi-natural vegetation such as woodland along run-off pathways to reduce evaporation and maintain water quality.
- Keep a strategy for dewpond restoration under review, due to their high vulnerability and extensive cost input required.
- Liaise with other protected landscapes to share knowledge and management techniques.

Adaptations that could aid other features

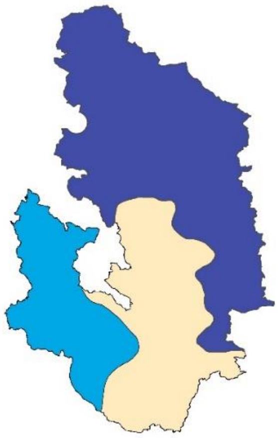
These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Restore key sites to link clusters and improve pond connectivity for species such as great crested newt.

Good water quality

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High



Feature assessed:

- Good water quality (Water Framework Directive)

Special qualities:

- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

The Water Framework Directive (WFD) aims for surface and ground waters to be of ‘good’ status. This status is assessed according to various factors such as the biological, hydromorphological, physical-chemical and chemical qualities of the water system.

The PDNP has approximately 400 km of surface water systems that fall within the WFD. These include rivers, lakes and reservoirs; and can be rated as high, good, moderate, poor, or bad.

A moderately productive aquifer underlies much of the PDNP, with many springs. Similar to surface water, these are rated under the WFD as good or poor. The impact of climate change on this ground water is assumed to be lower than for surface water as it is naturally filtered by rock up to 900 mm thick.

While the focus of this feature is mainly surface water, similar climate impacts are expected for groundwater.

How vulnerable is good water quality?

Good water quality in the PDNP has been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate current condition, and a moderate adaptive capacity.

Increased sedimentation and nutrient leaching may negatively affect water quality in the future. Furthermore, increased nutrient availability coupled with increased erosion and disturbance may facilitate increases in non-native invasive species. Good water quality in the PDNP has been attributed a moderate adaptive capacity. This is due to strong legislation and regulatory processes being in place and the potential for catchment wide management policies to positively impact water quality.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The poor condition of blanket bogs within the Dark Peak has led to high levels of water contamination, especially of dissolved organic carbon during high flow events. The Derwent Reservoir catchment is one such example, with high levels of dissolved carbon and colour in the reservoirs. Severn Trent water are trying to combat this by funding moorland restoration works on the surrounding hills. Further downstream, pesticides, herbicides and phosphates are issues in places such as the Tittesworth Reservoir catchment and the Wye catchment. Agriculture is a significant employer in the PDNP, with the 2,555 agricultural holdings giving an indication of scale of managed land.

PDNP watercourses are host to several non-native species, including signal crayfish, American mink, Himalayan balsam, Japanese knotweed and giant hogweed. These species affect water ecosystems and therefore good water quality as defined by the WFD. Transfer of water between waterbodies poses a risk of spreading such invasive species. Of the water bodies included in WFD assessment, approximately 40% are good quality, 60% moderate and 2% poor. This implies that water quality in the PDNP is generally reasonable, but has room for improvement. The majority of PDNP watercourses are too small for inclusion in the WFD, and so have not been assessed.

Groundwater bodies are generally rated as good, however the chemical status for some is poor (for example, the Derwent Carboniferous Limestone and the Derwent Secondary Combined catchments) due to mining and quarrying activity. Management of these groundwater bodies falls within the greater Humber River Basin catchment.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Nutrient changes or environmental contamination

Drier summers increase the risk of eutrophication, affecting both humans and animals. Associated with this is an increased risk of algal blooms, which can reduce drinking water quality. Due to these changes, water treatment requirements may require modification. Extended periods of dry weather may cause drying deep within peatlands of the Dark and South West Peak. Sudden increases in flow may then result in acid pulses through watercourses, potentially negatively affecting wildlife and the general trend for recovery from acidification. **[H]**

Increased annual average temperature may cause nitrogen flux due to soil decomposition resulting in increased nitrogen concentration in watercourses. Furthermore, pockets of anoxia may increase caused by greater biological oxygen demand. **[H]** Increased levels of nitrogen from atmospheric pollution may also lead to greater rates of growth of pond vegetation. Furthermore, many species associated with rivers and lakes are sensitive to changes in water chemistry. **[M]**

More frequent and intense storm events may result in spikes of nutrient contamination in watercourses due to fertiliser wash off and discharge from storm drains. **[M]**

Sedimentation or erosion

Wetter winter and drier summers may lead to the silting of reservoirs, both reducing water storage capacity and adversely affecting water quality. **[H]** Hotter summers may increase the likelihood sedimentation by increasing the chance of wildfires in plantations surrounding reservoirs. **[H]** An increase in intense storm events would compound sedimentation issues, increasing the quantity of fine sediment entering watercourses. **[M]** The speed at which river erosion processes such as bank collapse occur is likely to increase as extreme storm events become more frequent. **[M]**

Human behaviour change

Frequent droughts and floods, coupled with generally warmer temperatures may result in land use change - as current practices become unsuitable or new practices become possible in some areas. This could lead to pastureland being converted for arable use, new crops being grown and increases in the uses of pesticides, potentially affecting water quality. **[M]**

Hydroelectric energy schemes may become more prevalent as a climate change mitigation measure. Such schemes may require water to be diverted or current channels modified to house hydroelectric equipment, negatively affecting water quality as defined by the WFD. **[L]**

Hotter summers could result in an increase in water bodies being used for recreation, increasing the risk of pollution from litter and boat fuel for example, causing water quality to deteriorate. **[L]**

Invasive or other species interactions

Increased nutrient availability could result in increased plant growth rates. Water quality could be reduced in areas colonised by invasive species. **[M]** Increased annual average temperature may mean invasive marginal water plants are able to become more prevalent. If these plants then die back during the winter, banks may be exposed to increased erosion - reducing water quality. **[L]** More regular intense storm events could also increase erosion of riverbanks, providing greater opportunity for invasive species to colonise, reducing ecological condition of watercourses. **[L]**

Direct impacts of climate change

Increased annual average temperatures would result in more rapid mineralisation of organic matter and increased macrophyte growth in water bodies, therefore increasing evapotranspiration. Water quality may be reduced as these biological changes occur. **[H]** An increased water temperature coupled with periods of low water due to drought are likely to harm the biological status of waterbodies. Species adapted to cool water and fast currents such as Salmonids are at risk of loss or range contraction if suitable climate space moves upstream. In addition, shifts in phenology of aquatic invertebrates are likely to change the abundance of species through the disturbance of established food webs. **[M]**

What is the adaptive capacity of good water quality? *[Overall adaptive capacity rating: MODERATE]*

The huge improvements in water quality that have been made in the UK indicate that future recovery from damage is possible if human behaviour changes. However, it should be remembered that only a small percentage of rivers in England and Wales are currently considered pristine. **[H]** Rivers with modified banks and flood protection structures will be less resilient as they have lower potential to re-naturalise, and nationally these modifications are often the reason that rivers fail to meet WFD good status. **[M]** Some cold-water species may however be lost and unable to recover. **[H]**

Upstream management plays a role in water quality. Improved land management in the PDNP, for example blanket bog restoration, clough woodland establishment and environmentally sensitive farming practices at a landscape scale, have good potential to improve water quality despite climate effects. **[VH]** The PDNP also has a wide range of waterbody types with different characteristics, due to the diverse geology and topography of the area. This diversity increases the adaptive capacity of the water resource as a whole. **[H]**

There is strong legislation and regulation for monitoring and enforcement of water quality through the WFD. However, the Environment Agency only monitors 'main rivers' meaning smaller streams and rivers - where climate effects may be felt more strongly - may be at greater risk. Water companies have processes in place for triggering drought protocols to manage water levels. **[H]**

Agri-environment funding is currently available for habitat works that could help improve water quality at the catchment level, but complexity of schemes can reduce the incentive for landowners to take part. Changes in funding strategies towards a 'payment by results' approach may increase uptake in the future. Some water-related funding sources may be available such as those directed at Flood Risk Management or funding aligned to water industry drivers. However, there is currently much uncertainty surrounding the future shape of this type of funding. **[H]**

Key adaptation recommendations for good water quality:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Carefully manage water usage, especially during the summer.
- Establishment of riparian areas to maximise vegetation cover can help to reduce nutrient and sediment load entering watercourses.
- Restoration of soils can help to improve infiltration rates and reduce run-off and the risk of erosion.
- Buffer strips to trap sediment before it reaches a watercourse should be established wherever possible.
- Continue moorland restoration work to improve water quality.
- Restoration of natural processes across the catchment will improve watercourse health and therefore resilience to change.
- Minimise agricultural inputs, especially fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.
- Restoration of healthy soils in river catchments will increase infiltration of water and reduce runoff, thereby reducing sedimentation. Tree establishment is a known method to improve infiltration and reduce pollutant spread from runoff.
- Restoration of semi-natural vegetation on critical runoff pathways will slow the flow and reduce erosion.
- New hydroelectric power developments should not be allowed to prevent restoration of natural processes in river systems.
- Use of low nutrient livestock feeds will reduce contamination of the watercourse.
- Evaluate whether the introduction of beavers would be a feasible and appropriate method of delivering ecosystem service benefits such as flood mitigation, water quality and wet woodland creation.

Reservoirs

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:

- Reservoirs

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Reservoirs not only store drinking water for millions of people, but are home to various plant and animal species on both a permanent and seasonal basis. Aquatic plants, fish, insects, and birds all thrive within this habitat. Within the PDNP, there are 46 reservoirs covering more than 1100 hectares. 90% (42) of these reservoirs are found in the Dark Peak. These reservoirs are locally important for birds such as breeding common sandpiper and black-headed gulls, as well as rare mosses such as the dwarf bladder-moss which is found at a few sites.

How vulnerable are reservoirs?

Reservoirs in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate current condition, and a moderate adaptive capacity.

Land management practices, human behaviour, and invasive species currently affect the water quality in reservoirs and the species that live in and around them. Reservoir water levels, flow rates and quality may be compromised by climate stressors influencing sites at the catchment level. Habitat for wildlife in and around the reservoirs is likely to change. Reservoirs naturally fluctuate with weather events giving them good ability to recover. However a decline in reservoir water quality continues to pose the biggest threat to people and wildlife that rely on it.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Information on the condition of reservoirs as a wildlife habitat is sparse. Of the few reservoirs that have been assessed against the Water Framework Directive (WFD) within the PDNP, the water quality is mostly moderate, suggesting improvements can still be made.

Catchment run-off containing microbes and pesticides affects the colour and nutrient load in the reservoirs. Colour and dissolved carbon are a concern in the Derwent Reservoir along with pesticides in the River Derwent. Severn Trent is working with Moors for the Future Partnership to improve water quality through moorland restoration work and with farmers to reduce environmental contamination risks. Pesticides, bacteria and parasites such as cryptosporidium are a threat to people and also to other animals that use these reservoirs. Minimising sediment load and pollution risks in and around upland reservoirs is an ongoing process that is being carried out by water companies and land owners. This will ultimately benefit both people and wildlife.

Reservoirs are affected by land management practices right across the catchment. Nutrient and microbial enrichment is determined by fertiliser and slurry application, while erosion levels are influenced by stock numbers and machinery use. Intensive farming practices are particularly harmful to reservoir water quality as both ground and surface water makes its way downstream to reservoirs. Wildlife found in and around reservoirs is affected by water quality changes as well as disturbance. Recreational use of reservoirs for fishing, hiking, and cycling can interfere with the activity of some species. For example, common sandpipers at Ladybower Reservoir are vulnerable to disturbance in the breeding season. One study has shown that frequent disturbance can affect choice of nesting sites and the size of the breeding population, however breeding success rates at this reservoir were unaffected. Bird populations at smaller reservoirs may be more vulnerable as they have a smaller area of habitat available to which they can retreat.

Invasive and nuisance species are another threat to reservoir habitats. Plants are particularly problematic. New Zealand pigmyweed is present at Ladybower Reservoir, threatening native plant and animal life. Other reservoirs have large stands of rhododendron growing round the edges which can lead to acidification of the water and lower wildlife diversity. Water transfers from one waterbody to another are a potential risk for spreading invasive species. Risk assessments by water companies are in place to check both rivers and reservoirs before these transfers happen in order to mitigate this risk.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Nutrient changes or environmental contamination

Hotter, drier summers and wetter winters will affect the flow rates of water going into reservoirs. In summer the catchment is likely to stay drier for a longer period with low flow rates and decreased flushing. This may lead to higher concentrations of contaminants, increased risk of eutrophication, higher biological oxygen demand, and a greater frequency of algal blooms. In winter, erosion and run-off are likely to increase. Acid and heavy metal run-off from the uplands may further compromise water quality and increase eutrophication risk. The combined effect could be a change to the habitat and the species that are able to survive in it. A loss of plants could affect aquatic life, particularly fish that rely on them for food and water oxygenation. **[M]**

Intense flow in storm events could also affect reservoir water quality. Run-off from farmland and erosion of peat may increase nutrient load and heavy metal concentrations in reservoir water. While these effects will vary from catchment to catchment, reservoir condition under the WFD could deteriorate. Ecological status is based on both chemical and biological assessments, with the final result based on whichever has the poorer condition. **[M]**

Atmospheric pollution may affect water chemistry as well as growth rates of plants both in and alongside reservoirs. Increased carbon dioxide could cause the acidification of water bodies. Accelerated plant growth could lead to increased eutrophication that becomes harder to reverse.

Reservoir habitats are likely to be altered, with varying impacts on plants and animals that depend on them. **[M]**

Sedimentation or erosion

Hotter drier summers and periods of drought are likely to create warmer, shallower reservoirs with increased erosion in the surrounding catchments. Lower rainfall and increased evaporation may lead to changes in the thermal stratification of the water and lower dissolved oxygen levels. Phosphorous may also be released from the sediment back into the water due to deoxygenated conditions, increasing the risk of eutrophication. All of these reservoir habitat changes affect the wildlife that lives in and around them. Aquatic species, such as fish and invertebrates, may be affected by the reduced aquatic habitat and lower oxygen levels. Birds may benefit as it becomes easier to catch aquatic prey or they may be negatively affected as their food sources decline. **[M]**

Wetter winters with increased rainfall and erosion are also likely to affect reservoir water levels. Storage demands may become higher as larger volumes of water fall over shorter periods. Increased silt build up could reduce the total reservoir storage available for these peak rainfall times. Plants in the drawdown zones, such as mudwort and shoreweed, may be affected. Flood risks are likely to increase, threatening neighbouring and downstream areas. **[M]**

Human behaviour change

Reservoir water levels during drier summers are likely to be significantly lowered by demand for water. Water levels will already be low during drier or drought conditions, and will be further decreased by increased demand for water from the nearby towns and cities. PDNP reservoirs are already struggling to meet demand in dry years, and this pressure will likely only increase with climate change. **[L]**

Recreation near reservoirs is likely to increase as temperatures get hotter. Areas near water and shade could be in greater demand by a range of visitors such as anglers, sailors, and hikers trying to escape the heat. Increased visitor numbers around reservoirs will mean increased pressure on the surrounding infrastructure, and more frequent disturbance of local wildlife. Birds, such as common sandpipers, are particularly vulnerable in the breeding season. Repeated disturbance could affect breeding outcomes at some reservoirs. **[L]**

Land use decisions affect reservoirs and their neighbouring habitats. With increased floods and droughts forecast, land may become better suited to other uses. New crops may be introduced bringing with them new pesticides and changes to ploughing regimes. Water quality of reservoirs could change as a result. More harmful pesticides may deteriorate aquatic habitat condition and have an adverse effect on wildlife. Conversely lower toxicity pesticides or lower application rates may help improve water quality downstream. Intense ploughing regimes pose an increased risk of erosion and reservoir siltation. In other areas land may be abandoned, allowing scrub to develop. Increased vegetation cover may help wildlife habitat and diversity improve both on the edges of reservoirs and in the reservoirs themselves. **[L]**

Invasive or other species interactions

Warmer temperatures year round may aid the spread of invasive or nuisance species. Plants could benefit from a longer growing season and increased winter survival rates. Native aquatic and riparian plant species may be lost as more aggressive plants move in to take their place. New Zealand pigmyweed is already present at some reservoirs, and could expand its range which would threaten the ecological condition of reservoir habitats. **[L]**

Increased disturbance during storm events may create opportunities for invasive plants to colonise. Erosion of stream banks and gaps created in woodland adjacent to reservoirs could become vulnerable to invasion from species such as rhododendron. Vegetation changes surrounding the reservoir have a follow-on effect to the water quality of the reservoir itself. Some species, particularly those that cover a large area, may decrease the ecological condition of the reservoir. **[L]**

Other indirect climate change impacts

Hotter, drier summers are predicted to lead to an increased risk of wildfire. Many reservoirs in the PDNP are surrounded by plantation woodlands which are at risk. Loss of woodland adjacent to reservoirs would mean the loss of a key habitat utilised by birds and insects that thrive on the water's edge. Debris from wildfires in land surrounding reservoirs is also likely to lead to an increase in sedimentation and changes to water quality. The combined effect of changes on land and in the reservoir itself will see a change in the available habitat and the species that can thrive there. **[L]**

What is the adaptive capacity of reservoirs? ***[Overall adaptive capacity rating: MODERATE]***

Reservoirs in the PDNP are highly variable in shape and size. The limited storage capacity means that in periods of heavy rain and flooding, water reaches a maximum depth and storage options are restricted. Reservoirs are however by their nature more resilient than river extraction as they have water storage in dry periods. Due to the high density of existing reservoirs and topography of the area, there is limited space for the creation of new ones. **[M]**

Wildlife living in and around reservoirs has varying levels of dispersal ability. Fish and rarer plants are the most limited as they are often restricted to specific sites. Some reservoirs such as Ladybower are stocked with fish every year so they are less at risk from a climate stressor damaging the population. Birds are less restricted as they can move to other sites, however breeding sites may be limited for some species, such as the black-headed gull which currently only breeds at Longdendale. Loss of habitat may lead to a change in the bird species present. Woodland damaged by wildfire or storm events can be re-established, but the time it takes to grow back into a mature forest may affect species that utilise this habitat. Plants that grow on the edges of reservoirs in the drawdown zones should be able to move to new drawdown zones as long as the substrate remains similar. **[H]**

Reservoirs have a natural ability to recover from drought and flooding events provided regular checks are carried out on infrastructure. Water quality in reservoirs can potentially recover from change more readily than wildlife - impacts on which may be severe and long-term. **[H]**

Reservoir habitat quality is determined by management of the reservoir itself and management of the land surrounding it. Legislation is in place for the continual improvement and monitoring of water quality in the UK, under the WFD. The Environment Agency oversees this monitoring and identifies local issues that are contributing to poor water status. Water companies have their own monitoring and management plans in place for their reservoirs. Drought trigger zones are in place to help manage water levels at different sites. Adaptability in water use behaviour during dry periods can also help prevent water depletion. **[H]**

Financial resources are available for improving water quality at the catchment level. However schemes to improve habitats are often complex and there is limited incentive for private land owners to participate. There may be opportunities to improve existing schemes and compensation for ecosystem services in the future. Water companies also offer funds to support catchment level projects, such as the Boost for Biodiversity Fund available from Severn Trent. Water companies are also able to manage supplies and move water within the PDNP and import water in extreme scenarios. Reservoirs therefore have some protection from dangerously low water levels. **[M]**

Key adaptation recommendations for reservoirs:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Continue reservoir management of water levels with strict usage policies in place for drought periods.
- Continue catchment management to improve vegetation cover to reduce erosion and nutrient run-off entering reservoirs.
- Continue monitoring and control of non-native species in reservoirs and in neighbouring habitats.
- Improve access and recreation infrastructure to minimise habitat damage and wildlife disturbance.
- Increase riparian tree cover at reservoirs lacking in riparian vegetation, shade can help regulate reservoir water temperatures.
- Minimise agricultural inputs, especially slurry, fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

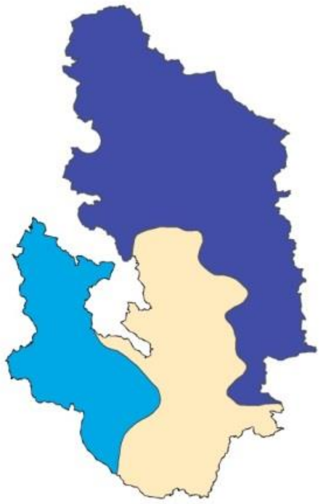
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Strengthen biosecurity measures by raising awareness: install signs at busy recreation sites, particularly where fishing and boating are common.
- Manage disturbance levels during bird breeding season, for example have access restrictions to vulnerable sandpiper territory.

Reservoirs and water management features

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature(s) assessed:

- Reservoirs and water management
- Water management – weirs, goyts, soughs and millponds

Special qualities:

- Landscapes that tell a story of thousands of years of people, farming and industry
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

Water management features, including reservoirs, dams, weirs, goyts, soughs and millponds, are found across the PDNP, giving an insight into former industries that were once prevalent, as well as the current supply of water to millions of people. Weirs were often created to harness water in millponds to power mills and other industries, and more recently to manage fishing. Soughs were created to provide underground drainage for lead mines which were found across the White Peak. A number of soughs are scheduled ancient monuments. Goyts are channels that were built to carry water, often feeding mills or powering pumps for water management in mines.

Reservoirs are a frequently a prominent feature in the landscape. Within the PDNP, there are 46 reservoirs covering more than 1,100 hectares. 42 of these reservoirs are found in the Dark Peak and four are found in the South West Peak. The largest is Ladybower Reservoir covering an area of 210 ha and holding up to 27.9 million cubic metres of water. Together with Howden and Derwent Reservoirs, this waterbody dominates the Upper Derwent Valley.

Reservoirs were built to provide a constant supply of drinking water to the major conurbations outside of the PDNP, where growing populations created a rising demand for water. While some date back to the 1800s, for example Damflask Reservoir, others were created much later, for example Errwood Reservoir in the 1960s. Severn Trent Water, United Utilities and Yorkshire Water now own and operate most of the reservoirs within the PDNP. Others are owned and operated by the Canal and River Trust, and a few smaller ones are in private ownership. The neo-gothic dams at Howden and Derwent are both Grade II listed.

For an assessment of the vulnerability of reservoirs as a habitat, please see the 'Reservoirs' section.

How vulnerable are reservoirs and water management features?
Reservoirs and water management features in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a variable current condition, and a moderate adaptive capacity.

Increased rainfall could impact on reservoirs and water management features if there is not enough storage or carrying capacity. The risk of flood to areas downstream could damage historic buildings and mills.

As the historic sites cannot be moved or relocated their adaptive capacity is moderate. While repairs or adaption may be possible they may result in the reduction in historic value.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

When some PDNP reservoirs were created, villages were lost as buildings were often left *in situ* and submerged. These historic features become visible again in periods of dry conditions. For example in 1976 and 1995 the lost villages of Derwent and Ashopton that lie under Ladybower Reservoir were revealed. Dry conditions for much of 2018 saw very low water levels again. This attracted a large number of visitors who went out onto the mud banks to see the relics. A small number of people damaged the remains, removing stones and tiles.

The reservoirs also often have strong cultural associations and significance (for example the link to the 'Dam Busters' training operations) and act as focal points for tourism and recreation.

Many weirs were created on rivers to facilitate fishing and to help provide waterpower to mills or other industrial processes that were located on riverbanks and in valley bottoms. In some areas, these weirs have been removed to allow natural river processes, losing these historic water management features. In other cases historic weirs and mill structures have been replaced with more modern equivalents. Although the original evidence of these water management features can be lost, some historical knowledge remains through archaeological surveys. A number of water courses themselves have also been altered. Historic engineering work has taken place to straighten or deepen channels which has potentially resulted in the loss of historic information.

Some soughs found in the White Peak are in a fragile and unstable condition. A number date back to the 17th century. The impressive Magpie Sough that served the Magpie Mine was driven with high explosives during the 19th century. Some soughs still function hundreds of years after they were driven – others have suffered blockages or collapse and no longer drain water from underground workings.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

If winters become wetter and rainfall increases there could be insufficient storage within reservoirs. This would increase the flood risk to neighbouring sites and downstream areas, damaging historic buildings, mills and water management features. Historic weirs may also be removed to reduce flood risk and create more natural river flows, resulting in a loss of historic fabric. There is also potential for damage to reservoir structures themselves. **[M]**

Historic structures that provide evidence of the industrial past such as soughs are often fragile and unstable. Any increase in storm events and rainfall could lead to damage from hydraulic action. **[M]**

Human behaviour change

Hotter, drier summers could see water levels drop - increasing the exposure of historical features such as submerged villages. This has already resulted in some damage to these features and could increase. **[M]** Hotter drier summers could also see a rise in tourist numbers visiting reservoirs and waterways and this could put pressure on infrastructure. While this may create more opportunities for local businesses, it is unlikely this would have a positive effect on these features. **[L]**

The expansion of carbon reduction schemes may mean soughs - historic mine drainage - are furnished with micro hydroelectric generators. These could see water diverted or channels modified. These historic features are often fragile and such changes could damage the structure and diminish their archaeological importance. **[L]**

Wetter winters may see the drawdown of reservoir levels in order to provide storage capacity during high rainfall events. This could cause erosion issues in some areas or potentially damage reservoir infrastructure. **(L)**

Sedimentation or erosion

Increased rainfall and wetter winters could increase the intensity of erosion and amount of deposition, resulting in damage to some water management structures. This would only be likely to occur along localised stretches of watercourses. These could be monitored along with their proximity to water management features, so adaptation efforts could be targeted. This means that flooding will mainly affect areas that are already susceptible, but during exceptionally large flood events then new areas that are currently rarely impacted could be affected. **[L]**

Fragile historic structures are at risk from an increased frequency of storm events. The resulting increase in erosion could cause the loss of evidence of our industrial past. Flash flooding in the Yorkshire Dales recently resulted in the loss of water features at an old lead smelting mill (a scheduled monument) demonstrating the vulnerability of these structures. [**M]**

Plantation woodland often found adjacent to reservoirs could be damaged more frequently by wildfire if summers are hotter and drier. The loss of the trees could increase erosion leading to greater siltation with a potential impact on reservoirs and other historic features. **[L]**

Invasive or other species interactions

Historic structures could be damaged by invasive species such as Japanese knotweed, as well as the growth of trees and scrub if warmer temperatures and increased precipitation lead to longer growing seasons. **[L]**

Nutrient changes or environmental contamination

The materials used to build some of the water management features, such as limestone in former mill buildings, could be susceptible to increased weathering due to atmospheric changes and higher acid water concentrations. The impact of this is likely to be limited. **[L]**

What is the adaptive capacity of reservoirs and water management features?

[Overall adaptive capacity rating: MODERATE]

Historic sites generally have a low adaptive capacity, as they are extremely difficult or usually impossible to relocate. Because there is usually no flexibility to reduce the amount of change they are exposed to, their vulnerability to climate change is higher. **[H]** If features are only damaged and not lost entirely it may be possible to repair or rebuild them, but it is costly and historic value could be diminished, especially by maladaptation. **[M]** However, within the PDNP the features in this grouping are dispersed over a wide area and this increases their adaptive capacity. Certain geographic areas will be more affected than others meaning that the likelihood of at least some features surviving is higher. **[M]**

A number of the historic features are given some degree of protection as they have listed status. This includes both Howden and Derwent Dams. Many of the features associated with water management such as the Masonry Weir at Curbar and the Wardlow Sough at Litton are scheduled monuments. However this is largely protection from human interference and may not help protect them from natural impacts. The Environment Agency provides policy guidelines for weirs - for example their removal, lowering and modification - as well as a review of best practice. Historic England provides policy guidelines for sustainable management of the historic environment. All these factors make sensitive adaptation measures more likely to be better managed on designated sites, but non-designated assets are extremely vulnerable. **[M]** Grants are available from a limited range of sources, and lack of funding will be a problem for many of these features. **[L]**

Upstream catchment management affects the flood risk of reservoirs and other historic features further downstream. There is significant scope to improve catchment management practices to slow and delay the flow of water from large rainfall events. Historic England also provides information on protecting industrial heritage sites such as mills from flood events, which could provide helpful adaptation information. **[VH]**

Key adaptation recommendations for reservoirs and water management features:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Water catchment management practices can be targeted at minimising flood risk and peak water flows. This may include increased woodland cover within the PDNP, restoration of blanket bog and sensitive farming practices, as well as drain blocking in headwater regions.
- Ensure surveyed features are included in Historic Environment Records and Selected Heritage Inventory for Natural England (SHINE) datasets.
- Nurture collaborative networks to build capacity for monitoring (e.g. volunteer groups).

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Research the most suitable adaptations for individual historic sites taking into account their situation and current use. This could include plans or physical barriers to reduce foot traffic, or physical reinforcement for the most valuable features. Care must be taken to avoid maladaptation.
- Undertake regular monitoring (including at landscape scale) of selected sites to identify those likely to be most vulnerable in terms of archaeology and ecology and to document change and help inform interventions where possible.
- Put forward key sites for scheduling.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

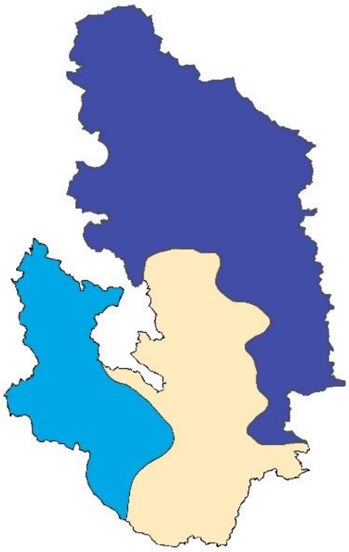
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Plantation woodlands in the uplands and those surrounding reservoirs should be managed to reduce erosion and slow run-off. Structural and species diversification with native broadleaved trees should be investigated. Encourage continuous cover forestry – to maintain higher levels of carbon storage and decrease soil losses.

Rivers and streams

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Features assessed:

- Rivers and streams

Special qualities:

- Internationally important and locally distinctive wildlife and habitats
- Vital benefits for millions of people that flow beyond the landscape boundary

Feature description:

The PDNP is covered by six different catchments: the Dove, Derbyshire Derwent, Don and Rother, and Aire and Calder, which flow into the Humber; and the Upper Mersey and Weaver Gowy, which flow into the Mersey.

These rivers and streams provide habitat for many species, hydrological function to agricultural land, a supply of fresh drinking water, and recreational opportunities to residents and visitors. 757.2 km of rivers and 3,361.5 km of streams are thought to run through the PDNP, though the exact length is difficult to calculate. Most PDNP rivers rise in the Dark and South West Peak moorlands, either as natural drainage from the blanket bog covered tops or as upwelling springs from the shale-gritstone margin. Some rivers rise from cave system catchments, such as the river Lathkill, which rises from Lathkill Head Cave. Most PDNP rivers change their character over their length. Rising as fast-flowing streams on upland slopes, Dark and South West Peak rivers are broad, slow-flowing and nutrient poor, while White Peak rivers generally have a higher nutrient status despite similar beginnings. Rivers often flow from one character area to another, with the normal progression being from upland streams to lowland gritstone river to limestone dale. Some limestone rivers may be dry for parts of the year and these are assessed in Vanishing Rivers.

How vulnerable are rivers and streams?

Rivers and streams in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a reasonable current condition, and a moderate adaptive capacity.

Most major rivers and streams are in a relatively good condition, with localised contamination and invasive species issues. The greatest effects on watercourses are likely to be from changes in precipitation cycles. Watercourses will become more variable, with higher flow in winter and lower flow in summer. Freshwater plant and animal communities are likely to be altered by these changes.

Higher temperatures are also likely to affect freshwater communities, with suitable climate space moving northwards and upstream, and warmer conditions causing changes in water chemistry. Rivers and streams are relatively adaptable, with freshwater species having developed dispersal techniques and the watercourses having diverse forms. Much legislation exists to protect and improve rivers and streams, and some funding is available for water quality and flood management works, which will improve river and stream resilience.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The condition of rivers is assessed under the Water Framework Directive (WFD) by the Environment Agency. In the PDNP, approximately 400 km of surface water systems qualify for assessment. Of the water bodies included in WFD assessment, approximately 40% are good quality, 60% moderate and 2% poor. This data implies that water quality in the PDNP is generally reasonable; however, the majority of watercourses are too small for inclusion and so have not been assessed.

Invasive species are more prevalent in rivers and streams than other PDNP habitats, having a greater effect on ecosystem function. Invasive American mink and signal crayfish in the watercourses predate or outcompete native species with knock-on effects on water quality. Some fish have been introduced to the PDNP for angling, such as the non-native rainbow trout. Invasive plant species such as Himalayan balsam and Japanese knotweed dominate riverbanks at the expense of native species, destabilising banks and increasing erosion during winter dieback. This erosion causes sediment input to watercourses, decreasing water quality. Transfer of water between water bodies by water companies has the potential to increase the spread of these invasive species, as does the use of water bodies for recreation.

Environmental contamination is a problem in many areas. At the headwaters of many streams contaminated peat is deposited into the watercourse, introducing heavy metal pollutants that wash downstream. Peat input also increases acidity and dissolved organic carbon concentration in moorland streams. Some areas of the White Peak are still affected by mine efflux, introducing zinc and other heavy metals to the watercourse through soughs and mine workings. Pesticides and phosphates from agricultural runoff continue to affect some rivers and streams, being of high concern in parts of the South West Peak. Agricultural land use has also increased sediment deposition in adjacent watercourses. Accidental inputs to river systems also pose a threat to water quality. These may be long-term inputs such as microplastics and pharmaceuticals, or larger single events such as the 2018 detergent spill in Buxton. These chemical pollutants damage the freshwater community, reducing their abundance and function.

River systems in the PDNP have been drastically altered by human constructions in many areas. Despite having no natural lakes, the PDNP now has many large water bodies in the form of reservoirs. Habitat conditions are altered by reservoirs, with more open water and minimal flow. Weirs and dams are also a barrier to species migration and dispersal, although in some cases they may be preventing the spread of invasive species. Reservoirs also control the flow of the rivers downstream, altering natural flow conditions. Channels have been deepened and straightened in some areas near towns, and streams altered for irrigation and historical mill function. The flow conditions of these areas will have been changed, altering the hydrology and community composition of the watercourse.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Increased average annual temperatures will cause a concurrent increase in water temperatures. As many PDNP freshwater species are cool-adapted, this is likely to have negative effects on river and stream communities. Invertebrate community composition will change, as well as their phenology; mayfly are sensitive to temperature changes, and their life cycles in the PDNP are known to be climate dependent. Salmonids are also at risk as cool water conditions are required for successful breeding. Some species may be able to move upstream to find cooler conditions at higher altitude, but species already at headwaters will be unable to move upstream and may be lost. **[H]**

An increase in atmospheric carbon dioxide levels may have negative effects on watercourses. Higher carbon dioxide levels may cause increased dissolution in watercourses, raising the acidity and thereby changing the species composition of aquatic habitats. More carbon availability may also increase plant growth rates, with greater nitrogen deposition during more intense rainfall events exacerbating this effect. Eutrophication could therefore become more frequent and less easy to reverse, reducing abundance of freshwater species and changing water chemistry, increasing the cost of water treatment for drinking water. **[M]**

Changes in annual precipitation cycles will affect the flow regime of rivers and streams. Wetter winters will cause increased flow and drier summers with more frequent drought will cause lower flows. As invertebrate communities are sensitive to flow rates, this could change the species composition at different times of year. Specialist species may be lost in favour of generalists that can tolerate a wider range of flow conditions. Prolonged low flow periods may be the most damaging. Less water would mean a reduction in habitat space, increasing competition and predation. Species such as water vole are sensitive to water depth and may be lost from very shallow areas. Shallow waters are also at greater risk of excess heating, causing thermal stress in freshwater species. Sections of river may seasonally dry out, especially at moorland headwaters. The top sections of many streams are currently seasonal, but these sections may expand and reduce habitat space. This could also limit the opportunity for species to adapt to warmer waters by moving upstream. **[M]**

Nutrient changes or environmental contamination

Higher water temperatures may lead to changes in water chemistry. Warmer waters may have increased biological respiration rates leading to lower dissolved oxygen levels, particularly at night when photosynthesis is not active. Combined with higher nitrogen inputs due to increased nitrogen flux in soil decomposition and increased fertiliser input from agricultural practices and organic input from livestock, some areas of watercourses may be susceptible to eutrophication during dry summers. As river flow promotes recovery from eutrophication via flushing, only drier areas of watercourses could be affected. River sections downstream of reservoirs could also be affected by algal blooms upstream. Low dissolved oxygen levels and areas of anoxia due to eutrophication will disadvantage species with high oxygen requirements such as fish. Community composition would therefore be altered, favouring species with lower oxygen requirements. **[H]**

Greater extremes in flow condition will be likely to have negative effects on water quality of watercourses. Low flows during summer may decrease the dilution of contaminants from sewage works outflow and agriculture, leading to increased concentrations of phosphorous for example. During high winter flows, increased runoff in the uplands will lead to acidic water, high dissolved organic carbon concentrations, and heavy metal pollutants being washed downstream. As a result, water quality and ecological condition may be decreased year-round. **[M]**

An increased frequency and severity of storm events may increase runoff, especially in areas with less vegetation cover. Runoff from agricultural land would increase siltation of watercourses and increase nutrient contamination and pesticide concentration. Runoff from degraded moorland would increase heavy metal pollution and peat particulate concentration. Reduction in water quality would likely lead to lower biodiversity and biomass in freshwater systems. **[M]**

Human behaviour change

Greater variability in river flows could lead to an increase in water infrastructure in the PDNP. Drier summers are likely to increase demand for water from already slow-flowing rivers. Increased abstraction could exacerbate the effect of drought, disadvantaging those species adapted to faster flows and removing some habitat spaces as smaller rivers run dry. Less water in the river systems will also increase the relative concentration of sewage outflows, decreasing water quality. Water being moved between catchments may also increase the spread of invasive species. Hard flood defences, dredging, and channel modification occurring as a result of wetter winters are likely to favour fast flowing species and create barriers to dispersal. Species composition may be altered, and freshwater habitat fragmented. **[H]**

As climate change advances, renewable energy sources may become more desirable. Many of the smaller watercourses in the PDNP have the potential to house small hydroelectric generators. The channel modification and water diversion associated with these developments, as well as the physical barrier of the generator, would have a negative impact on freshwater communities. Watercourses would then be unable to be classified as in good condition by the WFD unless re-categorised as heavily modified water bodies. **[M]**

Hotter drier summer conditions may lead to increased visitor numbers in the PDNP. This would lead to an increase in recreational use of water bodies. Greater disturbance of wildlife and bank erosion could increase, as well as pollution in the form of litter, boat fuel on reservoirs, and skin care products from swimmers. Popular sites such as Padley Gorge may decline in ecological condition. **[L]**

Greater extremes of precipitation will have an effect on land use surrounding rivers. More frequent and severe incidences of drought and flooding will cause the wetness of land around rivers to be less reliable. It may therefore be abandoned for parts of the year, leaving pastureland to become floodplain meadow or scrub. Watercourse ecological condition could potentially benefit from such changes. Alternatively, less stable conditions in riverside areas may lead to higher agricultural inputs to counter decreased productivity, damaging the ecological condition of watercourses. A move from pastureland to arable would increase runoff and therefore siltation of river systems. **[L]**

Other indirect climate change impacts

Warmer water temperatures may have a negative effect on ecosystem health due to reduced oxygen availability. Warmer waters hold less dissolved oxygen, meaning water chemistry is likely to change as temperatures rise. Some invertebrate species are more sensitive to oxygen availability than others are, so community composition is likely to change. Salmonid fish and other larger animals with high oxygen requirements are also likely to be affected. **[H]**

Sedimentation or erosion

An increase in intense storm events could lead to more sediment entering watercourses. Both runoff and flash flooding rise during storm events, both increasing the amount of sediment entering the water and spreading it further downstream. Fine sediment can fill up gravel banks, removing fish egg laying substrate and invertebrate habitat, as well as having direct effects on aquatic animals through blocking gills and other effects. Dissolved organic carbon and particulate carbon in the form of peat would be increased, changing the water chemistry and therefore the community composition. Water would also require increased treatment for consumption due to reduced water quality. **[M]** An increase in wildfire during hotter, drier summers could add to this effect due to opening up of bare ground and creation of fine sediment and ash. **[M]** Low flows in summer would reduce the ability of rivers to flush this sediment, making recovery more difficult **[H]**

Invasive or other species interactions

Increased average annual temperatures may lead to a longer growing season and increased winter survival for some plants. This may benefit faster growing and less cold-adapted invasive species more than native plants. Riparian invasives may become frequently dominant on riverbanks, while aquatic invasive species may also benefit from increased water temperatures. **[L]** Invasive species may also take advantage of the increased disturbance and erosion associated with a greater frequency and intensity of storm and flood events. Many invasive species die back in winter, further increasing erosion. Invasive species may then not only disrupt the riparian ecosystem, but also be damaging to the watercourse itself. **[L]**

What is the adaptive capacity of rivers and streams? *[Overall adaptive capacity rating: MODERATE]*

Some aspects of rivers and streams have low capacity to recover from damage. Species without an aerial life stage such as fish and crustaceans are unable to move beyond their catchment, and so could be lost from entire river systems. Even for those with high dispersal, structures such as weirs and dams may prevent them moving along watercourses. Some species may therefore be unable to move upstream into more suitable climate space as temperatures warm. The rivers themselves have low capacity for regeneration to their natural course, as human interventions will last a long time. However, increased winter flooding could enable rivers to reshape themselves to a more natural course. **[VH]**

Watercourses in the PDNP are relatively diverse. Small springs and streams emerge across the gritstone and shale moorland, with some others emerging from limestone cave systems. Larger watercourses flow as fast-flowing upland streams, slow and broad gritstone rivers, and limestone dales. Many rivers change character across their length, and join with other rivers as they flow through the PDNP. This diversity of form and bedrock increases the adaptive capacity of the overall system. **[H]**

Rivers and streams in the PDNP are relatively fragmented. Many rivers have been dammed to form reservoirs in their upper reaches, creating barriers to species movement and meaning that flow is controlled. Rivers are usually limited to connection within their own catchment only, with very limited connectivity with other systems. However, some rivers have been artificially connected, and water is occasionally moved between systems during drought. There is therefore some degree of connectivity between naturally separate systems. Watercourses have also been heavily modified in some areas, either for historical industry or for flood management in their lower reaches. Where channels have been widened and deepened or given an artificial bank these will likely pose some barriers to recovery or adaptation. **[M]**

Some funding is present to improve watercourse condition in the PDNP, including for catchment level habitat works. The Severn Trent Boost for Biodiversity Fund is one such scheme working on PDNP catchments. However, insufficient incentives currently exist for private landowners to take part on a large scale. The UK's exit from the European Union will also likely mean the end of the Common Agricultural Policy in the UK and presents potential to introduce payment for ecosystem services. **[M]**

Institutional support is available for rivers and streams in the PDNP. Legislation in the form of the WFD protects many rivers with the Environment Agency being the statutory body responsible for water quality. However, most watercourses in the PDNP are too small to be covered by the WFD, and these streams are likely to be the first affected by climate change. Many rivers and streams are also part of the Special Areas of Conservation (SACs) and Special Sites of Scientific Interest (SSSIs). The water companies in the PDNP are well-placed to conserve rivers, often owning many of the watercourses around reservoirs. Much research is funded by water companies, and drought and flood plans can provide guidance for future management. **[M]**

Management interventions that are beneficial for rivers and stream adaptation are relatively well-known. Practices such as restoring natural courses and reducing pollutant inputs are known to be beneficial to water quality, flood management, and ecosystem health. Lack of knowledge of effective interventions is not usually the factor preventing better management. Practical considerations such as insufficient funding and conflicting land use are more likely to be the reason for poor watercourse condition. **[M]**

Key adaptation recommendations for rivers and streams:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Restoration of natural processes across the catchment will improve watercourse health and therefore resilience to change.
- Consider removal of impoundments and weirs to restore natural river flow and improve species dispersal.
- Minimise agricultural inputs, especially fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.
- Restoration of healthy soils in river catchments will increase infiltration of water and reduce runoff, thereby reducing sedimentation. Tree establishment is a known method to improve infiltration and reduce pollutant spread from runoff.
- Restoration of semi-natural vegetation on critical runoff pathways will slow the flow and reduce erosion.
- New hydroelectric power developments should not be allowed to prevent restoration of natural processes in river systems.
- Use of low nutrient livestock feeds will reduce contamination of the watercourse.
- Block artificial drainage where possible.
- Manage invasive species, including botanical species and signal crayfish.
- Evaluate whether the introduction of beavers would be a feasible and appropriate method of delivering ecosystem service benefits such as flood mitigation, water quality and wet woodland creation.

Adaptations that could aid other features

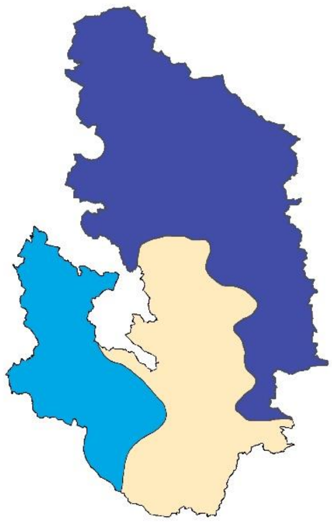
These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Creation of riparian shade through tree and scrub establishment will be beneficial to freshwater habitats, and may offset some of the effects of temperature rises.

Riverside meadows associated with meandering river channels

Overall vulnerability rating:

Very low	Low	Moderate	High	**Very High**



Feature assessed:

- Riverside meadows associated with meandering river channels

Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology

Feature description:

Riverside meadows are characterised by meandering river channels in a flat alluvial floodplain. This distinctive feature includes grazing meadows often with an area of wet grassland. At the water's edge there are sometimes hedgerow trees that can be scattered or quite dense.

This landscape character type exists along rivers throughout the PDNP. In the Dark Peak Western Fringe, meadows are found along the River Etherow and further south along the River Goyt. In the Derwent valley the riverside meadows are part of a narrow strip of floodplain that runs next to the river and is either one to two fields wide. It stretches continuously from below the Ladybower reservoir on the River Derwent, taking in Hope on the River Noe, Bakewell on the River Wye and running to Matlock just outside the PDNP boundary.

How vulnerable are riverside meadows associated with meandering river channels?

Riverside meadows associated with meandering river channels in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a variable current condition and a low adaptive capacity.

The extent of riverside meadows has been reduced over the last century with the ecological quality affected at many sites. Extreme weather conditions leading to both flooding and drought could have a significant impact on this feature. The adaptive capacity of river meadows is limited and there is no central organisation with responsibility for their condition.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

Changes to agricultural practices since the Second World War have affected the riverside meadows that are associated with winding river channels. There has been a reduction in the number of wet pastures and flood meadows, which provided ecological diversity and were potential resources to help with flood alleviation. The deliberate drainage of such areas has probably been a major factor in causing increased flash flooding in addition to reducing their value as wetland habitat.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Climate change could have a significant impact on riverside meadows, and remaining wetlands could be at risk of disappearing. Extremes of wetness and drought can both have a negative impact, and in fact, wetland communities can be more susceptible to frequent flooding than to drought. Such change could alter riverside meadow habitats in terms of their hydrology and the composition of species present. **[H]** Temperature change, in particular hotter summers, are likely to be a threat to the variety of habitats found in riverside meadows, through changes in growing conditions for meadow and wetland plants. As a result, the species composition of riverside meadows is likely to change. Hotter temperatures may mean plant phenology changes significantly - for example, flowering and seed setting taking place earlier in the season. **[M]** Extreme storm events may lead to an increase in the rapidity of some natural river processes, with meanders being cut off to form oxbow lakes particularly in the more sinuous stretches. This could increase the habitat and wildlife value of such areas. **[L]**

Human behaviour change

Riverside meadows are sensitive to any change in water levels and water availability. Drier summer conditions may affect both as water abstraction increases. This may result in a change in plant composition - with a rise in abundance of species associated with drier conditions, and a decrease in that of wetland species. **[M]** If flooding becomes more frequent in winter and summer during extreme events, it may alter the economic viability of agriculture in these areas. This could result in either increased intensification of management, or conversely the abandonment of some areas. If winter access becomes difficult, grazing levels may change. There could also be an increase in demand to use such areas for temporary storage of floodwater. **[M]**

A drive to generate renewable energy as part of carbon reduction schemes may mean that river channels or soughs - historic mine drains that run into rivers - are utilised and fitted with micro hydroelectric generators. This could result in water being diverted or channels modified. The addition of reservoirs into these landscapes is also a possibility. Such changes could have a negative impact not just on the aesthetic value of the area but also its ecological function. **[M]**

Hotter summers could increase pressure on recreational sites near water that also offer shade. An increase in the number of walkers and anglers, for example, may put pressure on infrastructure such as footpaths. This could in turn increase the risk of disturbance to wildlife such as water voles or some breeding birds. Hotter summers and a longer growing season may in turn affect agricultural practices, changing stock management if ground conditions become suitable for intensive grazing or perhaps conversion to arable land. Both these scenarios would be detrimental to the river system, water quality and aesthetics of the landscape. **[L]**

Invasive or other species interactions

A longer growing season due to warmer winters, coupled with changes to rainfall patterns may result in non-native species being able to colonise new areas and expand their range. This may mean that specialist wetland plant species lose out to species that are more adaptable to drier or fluctuating conditions. Ultimately, this could mean that certain native species are lost and replaced by non-native species, for example New Zealand pygmy weed. **[M]**

Changes in rainfall patterns and an increase in storm event frequency and severity are likely to disturb floodplain and riverbank soils, leading to a rise in colonisation opportunities for non-native species. Certain native species may be lost as a result. **[M]** Riparian invasive plant species may also come to dominate areas of wet grasslands. **[L]**

Nutrient changes or environmental contamination

Heavy rainfall and more frequent flooding events could lead to increased levels of phosphorus in floodplain soils and an increased risk of pollution. This could alter the composition of the plant community in riverside meadows with valued species lost and the habitat moving towards less valued inundation grassland. **[H]**

There could be further changes in plant community composition and habitats if the amount of nitrogen in the water increases as result of higher temperatures and reduced dilution during periods of low flow. In wetter meadows, nitrogen input from groundwater and floodwater could favour less desirable but more competitive plant species to the detriment of slower growing species that make up semi-natural meadow communities. **[M]**

Sedimentation or erosion

Riverside meadows and their associated infrastructure such as footpaths, historic field barns and mills are susceptible to both flooding and silt deposition. A rise in heavy rainfall events damage these features and riverside trees could be lost, further increasing the risk of erosion. Siltation could affect the species composition of wetland plant communities. **[M]**

What is the adaptive capacity of riverside meadows associated with meandering river channels?
[Overall adaptive capacity rating: LOW]

This is a highly fragmented set of features. Although there is some connectivity through the river channels, these riverside meadows are geographically specific – tied to wide, flat floodplains. This will present difficulties for riverside meadow species to move northwards or to higher altitudes in order to preserve the current character of the feature within the PDNP. Although the geological landform will remain, the habitats and species found in these areas are very likely to change. **[VH]**

Areas categorised as riverside meadows share key characteristics: a flat alluvial river corridor; meandering river channel with shingle beds and marginal vegetation; seasonally waterlogged alluvial soils; grazing meadows, often with patches of wet grassland and dense waterside and scattered hedgerow trees. There is limited diversity between the small number of sites in the PDNP, and this similarity will restrict the adaptive capacity, as the low variation means similar impacts will be experienced across the PDNP. **[VH]**

Grazing marshes may be less sensitive to atmospheric deposition of pollution than some other habitat types, although there is poor information available. The most sensitive areas are likely to be those close to channels, which may be less able to recover from change than areas further away. **[L]**

Currently there are some environmental stewardship options available that could help increase the adaptive capacity of riverside meadows. These include “Maintenance of species-rich semi-natural grassland”, “Restoration of species-rich semi-natural grassland” and “Wetland grazing”. Management which increases the quality of the current habitat will also increase its resilience to change in the future. However, the future of environmental land management schemes is highly uncertain. **[VH]**

No central organisation is responsible for the condition of riverside meadows in the PDNP. While the PDNPA management plan can recommend management options to improve condition and thus increase resilience, it has limited power to implement them. River catchment partnerships such as Derbyshire Derwent Catchment Partnership and the Upper Mersey Catchment Partnership are however a resource to influence positive management of floodplains. **[L]** It is likely that management options aimed at tackling non-climate effects can only ever have a limited impact, and so could only partially offset climate impacts. **[L]**

Key adaptation recommendations for riverside meadows associated with meandering river channels:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Look to improve the quality and species diversity of these grasslands through sensitive and flexible grazing and by limiting inputs of fertilizers and pesticides.
- Put protections in place to ensure hydroelectric generators are not installed in inappropriate locations where they would be detrimental to the function of the river system and the aesthetics of the landscape.
- Ensure tree strips along riversides are protected as much as possible in order to minimise the effects of erosion due to higher flows.
- Consider the impact on key views when planning adaptations.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Investigate the flood storage capacity of riverside meadows. Identify areas that could benefit from becoming temporary flood storage areas during times of high flow.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Allow natural river processes such as the formation of oxbow lakes to occur as much as possible and avoid channel modifications.

Accept changes to feature

These recommendations are about adapting ways of thinking to be accepting of inevitable change. While some changes may be negative, this also presents a chance to seek out any positive opportunities that may be caused by climate change.

- The potential for new reservoirs should be raised as an issue in the review of the Local Plan for the PDNP where this supports climate change adaptation, nature recovery and effective visitor management.

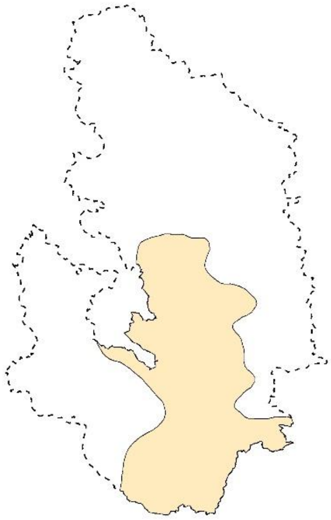
Vanishing rivers

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Vanishing rivers



Special qualities:

- Beautiful views created by contrasting landscapes and dramatic geology

Feature description:

Vanishing rivers are watercourses that disappear as they travel across the limestone bedrock, the main systems being the Hamps, Manifold, and Lathkill in the White Peak. For most of the year, these rivers can only be seen on the surface as dry riverbeds for much of their length. Disappearing under the ground, these rivers take a subterranean course through natural caves and mine workings before rising suddenly some miles further downstream. These rivers can only be seen as surface flow when in spate. Despite being dry, these rivers host a diverse freshwater community composed mostly of ephemeral and drought tolerant species. When the surface waters flow, opportunistic fish such as bullhead move in and become abundant, living elsewhere during the rest of the year. Some bullhead have been found without pigmentation at Ilam Risings. These fish presumably live at least partly in the underground section of the river. Vanishing rivers are a distinctive part of the White Peak landscape, forming some of the characteristic limestone dales and the obscure cave systems beneath.

How vulnerable are vanishing rivers?

Vanishing rivers in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with an unclear current condition, and a moderate adaptive capacity.

The greatest impact on vanishing river systems will be changes in rainfall across the year. Greater extremes in precipitation will leave rivers dry for longer and in higher flow when active on the surface. Vanishing rivers have some capacity for adaptation, as their characteristic community is relatively hardy and there are some financial resources available to increase their adaptive capacity.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

As river systems, the current condition of vanishing rivers is largely the same as that for rivers and streams generally. When flowing, vanishing rivers are subject to the same pressures as other watercourses in the PDNP. Invasion by non-native species such as the American mink and signal crayfish will affect these systems, but these will be disadvantaged in the dry reaches. Similarly, invasive plant species will affect vanishing rivers, but riverbank erosion effects will be lessened in dry reaches due to the less defined riverbank. Runoff from agricultural land is likely to introduce nitrogen and phosphorous contamination and pesticide pollutants, as well as siltation from fine sediment.

An effect specific to vanishing rivers is present in the Lathkill. Due to the river's emergence and flow through mines and mined sections of caves, heavy metal pollution affects some areas of the watercourse. The lower Lathkill has good or high status of biological and chemical elements apart from zinc. This is due to the blockage of Hillcar Sough, which has caused mine efflux to back up into the Lathkill rather than take its previous course into the Derwent.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Most climate change effects on vanishing rivers will be the same as for other watercourses assessed in the rivers and streams section. Only instances where the impacts are specific to vanishing rivers or differ from other PDNP watercourses are detailed here.

Direct impacts of climate change

Changes in annual precipitation cycles will prove very important for vanishing rivers. Greater rainfall in winter and lower levels in summer are likely to increase the variability of vanishing rivers, having negative effects on the river's biological communities. Many aquatic invertebrate species persist as a 'seedbank' of drought resistant life stages in the sediment during dry periods. Seedbank diversity reduces after longer dry periods, and abundance decreases as fewer invertebrates survive more intense drying. An increase in the diversity of terrestrial species occupying the dry river bed may occur, but this has not been studied. Higher flow conditions when the river is flowing may also decrease abundance and diversity. Not all freshwater species are adapted to high flow conditions, meaning the species assemblage present may be reduced. Many colonists also swim upriver to colonise, especially in the Lathkill where the source is a cave system. Extra flow may reduce the upriver dispersal ability of colonists such as bullhead. **[H]**

Increased annual average temperatures are likely to cause a change in the invertebrate community of vanishing rivers. Cool adapted species may be lost or replaced by southern species moving northwards with climate change. Many temporary river specialist species are found in the chalk rivers of the southeast that could replace PDNP species as climate space shifts, but dispersal across the gap between these two habitat areas may prove problematic. **[H]**

Human behaviour change

Drier summers may lead to increased demand for water abstraction. This would exacerbate low water levels during increasingly frequent drought. As a result, vanishing rivers would be dry for longer periods, having negative effects on the aquatic communities that utilise the habitat. This effect may however be small as vanishing rivers are not generally targets for water abstraction. However, some rivers that were previously perennial may become temporary during extremely dry periods. This may allow the vanishing river assemblage to increase in range and abundance, but at the expense of the usual river assemblage. **[H]**

Nutrient changes or environmental contamination

Longer dry periods may cause additional nutrient input to vanishing rivers during the wet period. During the time that no water is flowing on the riverbed, plants grow on the newly available space and plant debris such as leaves and branches collect. When flow resumes, this organic matter is picked up or decays in the water, increasing the nutrient content and organic matter in the watercourse. Longer dry periods may therefore allow more plant matter to accumulate, increasing the nutrient input to the temporary watercourse. **[L]**

What is the adaptive capacity of vanishing rivers? ***[Overall adaptive capacity rating: MODERATE]***

Vanishing rivers have some capacity to regenerate after extreme events. Species that inhabit the watercourse are already adapted to recolonise when the opportunity arises, through their drought tolerance or rapid dispersal ability. Therefore, changes that result in the watercourse being lost for longer periods may not result in complete loss of the species assemblage once suitable conditions return. **[VH]**

Vanishing rivers in the PDNP have reasonable connectivity. Some, such as the Hamps and Manifold, connect along their length. All are in the White Peak area and are not too far apart, meaning species with high dispersal such as those with aerial life stages have the potential for population movement between rivers. There are few artificial barriers along vanishing rivers as they are not ideal for retention of water. **[L]**

There is a reasonable diversity of vanishing rivers in the PDNP. While all are limestone rivers with some extent of underground flow, there are differences in their hydrogeology. Different river systems have different underground flows, with some travelling mostly through mine workings and some through natural caves. Vanishing rivers also flow above ground for different lengths and at different times of year. **[L]**

Some funding sources are available for work on rivers at a catchment level. However, these are unlikely to take into account the unique situation of temporary rivers, in which the river does not exist as overground flow for much of the year. Vanishing rivers may therefore remain less desirable for funders, as they do not fit the typical river structure. **[M]**

Vanishing rivers benefit from some of the same legislative and organisational support as other watercourses in the PDNP. Some rivers are covered by the Water Framework Directive and so are closely monitored. They will however be likely to receive less support from water companies, being on a porous limestone bedrock and so less useful for abstraction. **[H]**

There is a general lack of understanding of temporary streams across the UK. PDNP vanishing rivers are one of the better studied systems, but still more research is required to effectively implement adaptive management. Some recent studies have aimed to quantify the invertebrate community of these systems, as well as the ecosystem services they provide. Such work will be needed to understand these systems and how to preserve them in the future. **[M]**

Key adaptation recommendations for vanishing rivers:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- More research is required to better understand the hydrology of low flow river systems and their interaction with surface and underground workings associated with mining.
- Consider restoration measures to reduce the impact of human activity, such as features in mining (soughs) diverting water to different catchments. Especially where impacts are known.

- Restoration of natural processes across the catchment will improve watercourse health and therefore resilience to change.
- Consider removal of impoundments and weirs to restore natural river flow and improve species dispersal.
- Minimise agricultural inputs, especially fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.
- Restoration of healthy soils in river catchments will increase infiltration of water and reduce runoff, thereby reducing sedimentation. Tree establishment is a known method to improve infiltration and reduce pollutant spread from runoff.
- Restoration of semi-natural vegetation on critical runoff pathways will slow the flow and reduce erosion.
- Use of low nutrient livestock feeds will reduce contamination of the watercourse.
- Manage invasive species, including botanical species and crayfish.
- Consider the impact on key views when planning adaptations.

Adaptations that could aid other features

These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Creation of riparian shade through tree and scrub establishment will be beneficial to freshwater habitats, and may offset some of the effects of temperature rises.

5.9. Wildlife

Wildlife

	Potential impact	Adaptive capacity	Overall Vulnerability score	Page number
Adder	High	Moderate	**High**	295
Aquatic invertebrates	High	Moderate	**High**	299
Bilberry bumblebee	High	Moderate	**High**	305
Curlew	High	Low	**Very High**	309
Dipper	High	Moderate	**High**	314
Dunlin	High	Low	**Very High**	319
Golden plover	High	Moderate	**High**	325
Great crested newt	High	Moderate	**High**	330
Lapwing	High	Moderate	**High**	335
Merlin	High	Low	**Very High**	341
Mountain hare	High	Moderate	**High**	347
Pied flycatcher	High	Moderate	**High**	351
Ring ouzel	High	Low	**Very High**	355
Short-eared owl	High	Moderate	**High**	360
Snipe	High	Moderate	**High**	365
Swallow	High	High	**Moderate**	370
Twite	High	Low	**Very High**	375
Waxcap fungi	High	Moderate	**High**	381

Please refer to Section 5.1 ‘Navigating the Feature Assessments’ for any help understanding the feature assessments on the following pages.

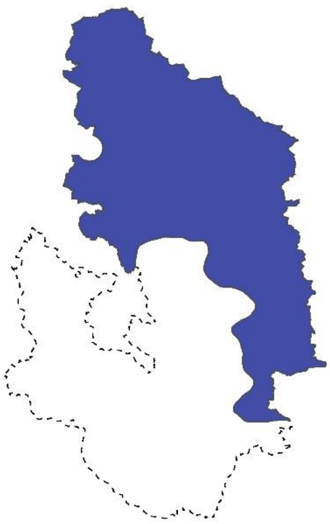
Adder

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Adder (*Vipera berus*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The adder is the UK's only venomous snake. It is easily recognised by the distinctive dark zigzag pattern down its back. Found in open and mixed habitats such as grasslands, woodlands, and heathlands, adders occupy a limited range in the PDNP. Population estimates are difficult; but there remains a highly concentrated group of adders in the Eastern Moors area – now representing the stronghold for adders in the PDNP. In marked decline across the UK and northern Europe, every adder population is nationally and internationally important for the future survival of the species.

How vulnerable are adders?

Adders in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor and fragmented current condition, and a moderate adaptive capacity.

The PDNP adder population currently appears to be relatively stable despite its reduced and fragmented nature. Small adder populations are likely to be more vulnerable than larger, more stable populations. Adders have some scope for adapting to climate change, particularly if habitat management is continually improved. Translocation to new sites may also be an option for securing a larger population range within the PDNP.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The UK adder population and distribution has declined dramatically since the 1970s and 1980s. Continued decline has led to some experts predicting they could go nationally extinct at all but a few sites in the next few decades. The main population in the PDNP is in the Eastern Moors where the population, thought to number around 300, is currently stable or only in slight decline. Other adders in the PDNP are limited to single sightings where individuals or small populations are extremely vulnerable.

Public pressure and disturbance combined with habitat management and fragmentation are reported as the main drivers behind the marked decline in numbers. Historic land management such as burning, over-grazing, and predator control likely determined the current distribution of adder within the PDNP. Overgrazing is now considered low risk, but trampling of habitat by cattle is still an issue at some sites. Habitat fragmentation, inappropriate habitat management, and disturbance by people and dogs is still of concern. However, the main current risk factor is the destruction of habitat, especially by wildfire and erosion. Individuals may be killed by wildfire, inbreeding risks may increase, and populations may suffer due to increased exposure to predators and a loss of food sources. Erosion of peat and soils may create large bare patches that adder are unlikely to use as the peat can get too warm and lack the vegetation cover they need to hide.

Other risk factors for adders are predation and disease. Animals such as buzzards, pheasants and dogs are known predators of adders. While predation by these animals has been confirmed, there is no evidence that is a limiting factor for population sizes. Little is known about diseases affecting native reptiles but testing has confirmed instances of Snake Fungal Disease and salmonellosis in adders, though the level of risk to the species is currently unknown.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

As reptiles, adders are sensitive to changes in air and soil temperatures. During warmer winters and hotter summers, soil temperatures are expected to rise particularly in areas of bare ground that are exposed to more sunlight. Adders may benefit from the warmer climate in some areas, with improved growth rates, longer activity periods, and increased fecundity success. However, winter mortality rates may worsen if shorter hibernation periods are followed by cold snaps. Adders may be more vulnerable to extreme weather events or more at risk from human disturbance if they are active for more of the year. **[M]**

Changes to rainfall patterns could alter grassland and moorland habitats that adders rely on. As vegetation cover decreases in some areas and increases in others, the change in habitat structure could affect adders as well as their prey. Water and heat stress may negatively affect adders and their embryos. Other extremes such as flooding may drown some individuals but are less likely to have long-term effects. **[M]**

The growth rate of plants can be influenced by atmospheric composition and nutrient deposition. With a predicted rise in carbon dioxide, it is possible that increased vegetation cover will benefit adders. In areas with less vegetation management, they may gain extra protection from predators and disturbance. However, the benefits gained from this vegetation increase are limited, as adders still require some open spaces for basking. **[L]**

The climate space for a species can be estimated by modelling temperature and precipitation levels under different emissions scenarios, taking into account known species distributions. In both low and high emissions scenarios, modelling predicts that there will be huge losses of appropriate climate space for adders across the UK, especially in England. In the PDNP, climate space could increase under a low emissions scenario but it is likely to be lost or transient under a high emissions scenario. **[M]**

Other indirect climate change impacts

Wildfires are predicted to become more frequent with hotter, drier summers. The loss of large areas of moorland vegetation could be detrimental as moorland habitats provide cover for adders and their prey. The adder population may decrease as individuals and their prey are killed in fires. Given the relatively small extent of the PDNP left with adders present, the whole population could be at risk if wildfire is widespread. **[M]**

Human behaviour change

Adders are sensitive to disturbance, whether from passing visitors or land use changes. As tourist numbers in the PDNP are expected to increase on sunny days, basking adders are more likely to be disturbed by people and dogs as the numbers of these passing visitors increase.

Land use choices will also affect the extent of disturbance to adders within their habitats. In areas where grazing intensity decreases or management is reduced, adders may gain new habitat where they can thrive with lower levels of disturbance. Conversely, in areas with increased disturbance or dramatic habitat changes such as vegetation loss across a wide area, adders may lose some of their habitat and have an even more restricted range within the PDNP. **[M]**

Sedimentation or erosion

Vegetation cover is necessary for adders to hide. As extreme events such as flooding, landslides and drought become more common, some adder habitat could potentially be altered. Vegetation loss that leaves areas of ground exposed poses the biggest risk. Adders with less cover are more likely to be disturbed by humans and animals, are more vulnerable to predation, and may lose some of their foraging habitat. Populations may also be affected as some individuals are killed and there is increased fragmentation between existing groups. **[L]**

Invasive or other species interactions

Stressed animals are more susceptible to disease and predation. With warmer, wetter winters predicted, diseases such as Snake Fungal Disease may become more of an issue for adders. Other new snake diseases could also be introduced from Europe as the climate becomes more suitable.

Predator numbers are likely to vary and some predators may gain an advantage if adder habitat is altered and adders are left with less cover. An increase in predation could negatively affect population size. **[L]**

What is the adaptive capacity of adders? ***[Overall adaptive capacity rating: MODERATE]***

Within the PDNP the adder has been confined to a small area of its previous range. Despite the highly fragmented population that remains, there is potentially viable habitat available further north. Within the PDNP, the main obstacles to their expansion are their small home range and the roads that separate habitats. However, population movement could be encouraged through translocation to other suitable sites. Structural diversity is a key habitat requirement that will enable adders to cope with thermal extremes. **[H]**

Large population sites are vital for the future survival of the species. Adders are slow to recover from any losses of individuals, as they only reproduce every two to three years. Small populations are at a much greater risk of extinction from a single event such as flooding or wildfire. Where large areas of habitat are lost, it can be difficult for adders to recover if there is nowhere to disperse. Although adders are generalist species, a mix of plant species is needed to promote a diversity of prey species. A recent site survey has suggested that monoculture bracken may be a limiting factor and adders do better at sites that are more diverse. **[M]**

Adders are protected under the Wildlife and Countryside Act (1981), where killing, injury and trade are an offence. They are a biodiversity priority species under the Natural Environment and Rural Communities (NERC) Act 2006, which gives them further protection and encourages conservation action by relevant local authorities. The incorporation of habitat requirements into management plans is one way populations may be enhanced in the face of climate change. **[H]**

Habitat management plays a significant role in the viability of adder populations. One study showed that appropriate management was a positive factor at more than 40% of UK adder sites. Management of adder habitat on the Eastern Moors is now carefully carried out to minimise disturbance. Burning has stopped completely and cutting is only done during hibernation. Continual management of PDNP adder sites is likely to help offset climate change stressors. **[H]**

Funding opportunities may be available through Amphibian and Reptile Groups or Wildlife Trusts. Most work on adders is currently done by volunteers. **[M]**

Key adaptation recommendations for adders:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Continue improving habitat condition: ensuring there are suitable sites for basking, hibernation, and breeding. This will help to make existing populations more resilient.
- Continue gathering sightings and creating photo database of individuals.
- Increase habitat connectivity: to aid dispersal and breeding.
- Investigate translocation to new sites. Further research is required.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

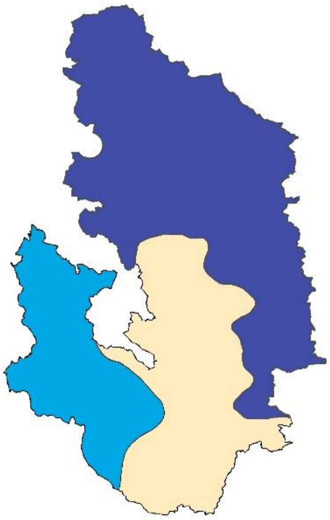
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Limit disturbance at known sites (particularly at hibernaculum during winter).
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Aquatic invertebrates

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature assessed:

- Aquatic beetles and invertebrates

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Aquatic invertebrates are a broad category, covering all non-vertebrate animals living in PDNP streams and ponds. This assessment focusses mostly on freshwater insects, insects whose larvae have an aquatic stage, and native crayfish. Caddisflies, stoneflies, and mayflies are common freshwater species, their larvae sharing habitat with dragonfly nymphs and water beetles. The native white-clawed crayfish can be found in some PDNP streams and still water bodies. Other invertebrates present in the PDNP include freshwater bivalves such as the swan mussel, water snails, and freshwater shrimp. Some crustaceans can be found living in the subterranean waters of PDNP caves and mines.

Freshwater invertebrates can be found in most water bodies in some form. Species with high dispersal potential, such as those with a flying adult stage, being able to make use of even isolated and ephemeral water bodies. Rivers and other watercourses contain the most diverse assemblage of invertebrates, being a large and well-connected habitat. These areas are where crayfish and larger invertebrates will be found. Dewponds are also important invertebrate habitat, being some of the only areas of standing water in the White Peak.

Freshwater invertebrates play a vital part in the ecosystem, an essential link in the food chain of freshwater as well as terrestrial systems. Fish and other aquatic animals depend upon freshwater invertebrates for their food. The flying adult stage of some freshwater invertebrates is also an essential part of the diet of many birds, such as the pied flycatcher. Freshwater invertebrates are also an invaluable indicator of water quality, a healthy community indicating absence of pollution or nutrient enrichment.

How vulnerable are aquatic invertebrates?

Aquatic invertebrates in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables and a poor current condition, but with a moderate adaptive capacity.

Aquatic invertebrate populations in the PDNP likely mirror the national decline, with many species threatened by pollution and invasive species. As aquatic organisms, these invertebrates depend on good water quality, and so they are most sensitive to climate change effects that reduce water quality such as increased siltation and pollution. Changes in annual water cycles, such as altered flow rates and drying out of some habitat, are also likely to have a significant effect. Aquatic invertebrates have a moderate adaptive capacity due to their high diversity and dispersal, and may benefit from economic and institutional efforts to improve water quality.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Freshwater invertebrates are threatened globally, with 25% of species under threat of extinction, though sparse data for the PDNP makes it difficult to assess whether this is the case locally. Rivers and streams in the PDNP are heavily impacted by their proximity to human population centres and agricultural land, mostly in the form of pollution and sedimentation. The main bodies of standing water in the White Peak are dewponds. Despite being sheltered from some human impacts, they are still at risk of loss due to abandonment or poor management. As many as 50% of dewponds have been lost since the 1970s, and more may be lost if not maintained.

Invasive species are a persistent problem, especially for crayfish. The signal crayfish has displaced native white-clawed populations and spread crayfish plague. As a result, white-clawed crayfish have been lost from most areas of the PDNP. Only a few small populations are still present in some streams and still water bodies. Introductions to so-called ‘ark sites’ are underway. Other invasive crustaceans such as the zebra mussel, killer shrimp, and demon shrimp have also been found in PDNP waters. Invasive Himalayan balsam is a persistent problem, shading areas near riverbanks and increasing siltation of the water via bank erosion.

Pollution of PDNP waters is pervasive, and has a greater immediate effect on invertebrates than larger freshwater species. Rivers such as the Derwent have their headwaters in the Dark Peak, where heavily contaminated and acidic peat is washed into the watercourse. Heavy metals in the peat are soluble in acidic water and so can be carried downstream through the PDNP. As these heavy metals can be toxic even at low concentrations, their effect is felt far from the source.

Runoff from agricultural land can carry with it a variety of harmful chemicals, which are washed into streams to the detriment of invertebrate populations. Pesticides such as neonicotinoids are designed to kill insect crop pests, and so have a pronounced effect on the insect part of the aquatic assemblage. Sheep dip has played a similar role on pastureland, with the now banned cypermethrin able to cause damage many kilometres downstream. Herbicide use has been harmful, increasing nitrogen availability and encouraging algal blooms, making watercourses unsuitable for many freshwater invertebrates. Fertiliser runoff, including nutrients from slurry, has had a similar effect in the form of nitrate pollution but can also cause phosphates to enter the watercourse. Phosphates increase the growth of diatoms and make river sediments and water quality unsuitable for many invertebrates.

Pollution near population centres, especially downstream of wastewater treatment facilities, is a particular problem. Pharmaceuticals can have detrimental effects on invertebrates, with some chemicals commonly found in household products with anti-microbial properties affecting smaller invertebrate species and bioaccumulating in larger ones. Microplastics, found in the same areas, may also cause similar problems with bioaccumulation. Phosphates can also be released from industrial sites and wastewater treatment sites, having the same effects as fertiliser runoff on water quality and river sediment. Accidental releases of industrial chemicals such as washing materials have the greatest negative effects, eliminating invertebrates from some areas temporarily.

Silt can enter the watercourse from various sources, including runoff from agricultural land and roads. As many PDNP roads follow the course of rivers, this may be a significant effect. High siltation can damage invertebrates in numerous ways including burial, abrasion, and clogging of gills. This runoff can also contain de-icing chemicals during winter that can reduce diversity downstream for some distance.

Modifications such as weirs and dams that change river course and flows can change invertebrate communities and prevent the spread of invertebrates upstream. Impoundment of water behind these structures also creates poor habitat for invertebrates, and build-up of sediment limits benthic riverbed habitat. Bridges can also be detrimental to some invertebrates, slowing the spread of adult mayflies upriver. Conversely, they may also provide good habitat for caddisflies. Artificial light can draw adult mayflies away from watercourses, preventing them from completing their life cycle. Roads can also have this effect to a lesser extent by reflecting horizontally polarised light.

What are the potential impacts of climate change? *[Overall potential impact rating: HIGH]*

Direct impacts of climate change

Increases in annual average temperatures may have a significant effect on freshwater ecosystems. Higher water temperatures will at best change the species composition and at worst cause the loss of many invertebrate species. Spring macroinvertebrate numbers could be reduced by about 20% for every $1^{o}C$ rise, and a $3^{o}C$ rise could result in a reduction of over 40%. Some species may be replaced by invertebrates better adapted to the new conditions, meaning that ecosystem function may persist but community composition is altered. As climatic ranges contract upwards in altitude and latitude, the PDNP may prove an important refuge for those species lost in more lowland environments. **[H]**

Changes in annual flow patterns could affect freshwater invertebrate populations in numerous ways. Increased winter rainfall would cause a higher flow rate in most rivers. Invertebrate communities are sensitive to flow rate, so this could be detrimental to some species and cause a change in the community composition. Conversely, reduced summer rainfall and increased drought would have the opposite effect: slower flows and reduced habitat would favour different species to those benefitting from faster winter flow. Variable systems, such as the Lathkill and other ‘vanishing rivers’ would be affected most by these changes. Drought may also dry out ponds, especially dewponds with low natural water input. These ponds may become ephemeral, and lose some of their invertebrate community. Species with high dispersal ability and those able to survive seasonal drying out may persist. Reduced water levels in ponds also results in lower dissolved oxygen content, which can have a significant effect on invertebrate communities. **[L]**

Sedimentation or erosion

Drier ground conditions in summer followed by severe summer storms and increased winter rainfall is likely to lead to greater erosion and runoff. Runoff from bare ground in pastoral and arable land, as well as from roads via drains would increase siltation and sedimentation in water bodies. Siltation damages freshwater invertebrates and reduces habitat, especially shallower benthic habitat, by settling on river and pond beds. The speed at which this material enters the water system will also likely increase, reducing the potential to remove it by natural or artificial means. **[H]**

An increase in summer wildfires would compound this effect. Fires open up bare ground and introduce silt in the form of ash from burnt plant matter, potentially increasing siltation and sedimentation during the summer months, especially in the Dark and South-West Peak. **[L]**

Nutrient changes or environmental contamination

Increased atmospheric carbon dioxide and nitrogen deposition may lead to a higher growth rate in riverbank plants. This may have effects on freshwater invertebrate populations due to increased shading of some sections of the riverbank. Shading of the water leads to a different invertebrate community, meaning some rivers would have a changed species assemblage. However, the extent to which this would be a problem is unclear, as some shading of the riverbank is good for macroinvertebrate communities, and shading may offset some of the warming effects of climate change. Increased plant growth may also lead to increased nutrient input from fallen leaves. However, this effect would likely be negligible compared to the existing issues of nutrient input from agricultural land and wastewater. Eutrophication could also increase due to contamination, which can decrease freshwater invertebrate populations greatly, especially mayflies. **[H]**

Reduced summer flows and lower water levels in ponds may amplify existing issues in the water bodies. A smaller body of water, moving more slowly through the system, would have higher concentrations of both nutrients and pollutants. The negative effects of these inputs would be heightened, leading to reduced invertebrate abundance and changes in community composition as tolerant species outcompete sensitive species. Eutrophication may also increase in the warmer, nutrient loaded waters. Conversely, higher winter flows could cause more flushing of the river systems, leading to lower nutrient availability during the winter months. **[L]**

Increased runoff due to winter rainfall may also increase nutrient loading of water. This could occur through increased fertiliser entering the watercourse, and eroded soil deposited in rivers and streams. This again would alter invertebrate communities, and enhance other effects such as eutrophication. **[L]**

Invasive or other species interactions

Increased annual average temperatures may lead to invasive species moving into the PDNP and increasing in prevalence. Those invasive species already present that are from warmer climates will have an even greater competitive advantage. Species that are not yet invasive may become so due to conditions that are more favourable. **[L]**

Increased flooding may connect water bodies more regularly and over greater distances. This would provide greater opportunities for invasive species present in one water body to colonise new areas. This increased spread would allow invasive species to replace native species over a greater area of the PDNP. **[L]**

Human behaviour change

Hotter, drier summers may lead to increased abstraction of water to supply nearby towns and cities. This could be in the form of more demand on existing installations or creation of new installations to keep up with demand. This would lower flow rates in some areas and provide physical barriers to dispersal for some invertebrate species, changing the community composition and fragmenting habitat. Some rivers may also be culverted, diverted, or concreted for flood prevention. This would reduce the habitat available to most species and further reduce connectivity. Models suggest that caddisfly populations have a variable response to climate change mitigation measures, with some worse off. **[L]**

Other indirect climate change impacts

Increased average water temperatures may also have effects on oxygen and carbon availability. Warmer water holds less dissolved oxygen and organic carbon, meaning that conditions are likely to change for freshwater invertebrates as temperatures rise. Some invertebrates require high oxygen levels so these species could be lost, but microbial activity is also heavily dependent on oxygen and carbon levels. As a result, many small invertebrates could have reduced food availability as the bottom of the food chain is reduced. This change in the microbial community would have knock on effects on all trophic levels, leading to reduced abundance and change in community composition of freshwater invertebrates and the species that depend on them. **[L]**

What is the adaptive capacity of aquatic invertebrates? ***[Overall adaptive capacity rating: MODERATE]***

Freshwater invertebrate populations can recover from high levels of devastation, mostly through their high dispersal ability. Studies from abroad have shown that populations can recover from complete loss in around a year. Pond invertebrates adapted to small and ephemeral habitat will be much faster to recover than river species such as white-clawed crayfish, especially as these have already been lost from many rivers. **[H]** The diverse assemblage of freshwater invertebrates found in the PDNP will bolster their recovery ability. **[L]**

Freshwater invertebrate habitats have generally high connectivity. Although freshwater systems could be seen as fragmented, especially when it comes to ponds and other small water bodies, the invertebrates themselves often have excellent dispersal. Some species, such as the white-clawed crayfish, will only be able to travel short distances between water bodies. Others, such as some insects with flying adult stages will be able to colonise any suitable habitat. Artificial structures such as dams, weirs, and bridges create some barriers to dispersal, but can be removed or modified. **[L]**

Some funding is available for habitat works, meaning water quality can be improved at a catchment level. The current complexity of environmental land management schemes may mean that the incentives for landowners to take part are limited. Catchment partnerships may be a good resource to influence whole system management. The withdrawal from the EU Common Agricultural Policy may provide an opportunity to improve payment for public goods, and therefore ecosystem services. **[M]**

Some institutional support is available for freshwater invertebrates in the form of projects such as 'Crayfish in Crisis' in the South-West Peak. Strong legislation in the form of the European Union Water Framework Directive and strict regulatory processes monitor water quality and can enforce better practice, although this only applies to main rivers. Institutional guidance on management will be vital to success in conserving these habitats. **[M]**

Water management will be important for invertebrate populations in the future. Flow-slowing measures will generally benefit invertebrates, but artificial flood prevention measures can fragment habitat. Not enough is known about conservation of freshwater invertebrates to be fully effective in response to future changes, but it is likely that whole catchment practices will be needed to be effective. **[L]**

Key adaptation recommendations for aquatic invertebrates:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Contamination of watercourses must be taken seriously, and efforts made to reduce the entry of fertilisers, slurry, pesticides, pharmaceuticals, road runoff, and wastewater pollutants.
- Changes or modifications made to river channels (for example for renewable energy sources) must be made with aquatic invertebrates in mind.
- Floating dead wood and woody debris is invaluable invertebrate habitat. Allow natural processes to occur in river systems, and allow for a less 'tidy' looking environment.
- Conduct surveys of invertebrate communities across the PDNP. Dewponds may be of particular interest.
- Remove impoundments and allow natural meandering where feasible and retro-fit artificial berms or meanders to improve natural sediment transport.
- Buffer strips to trap sediment before it reaches a watercourse should be established wherever possible.
- Combatting the spread of invasive non-native species will be key to the recovery of many invertebrate populations, especially the white-clawed crayfish.
- Continue dewpond restoration work.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

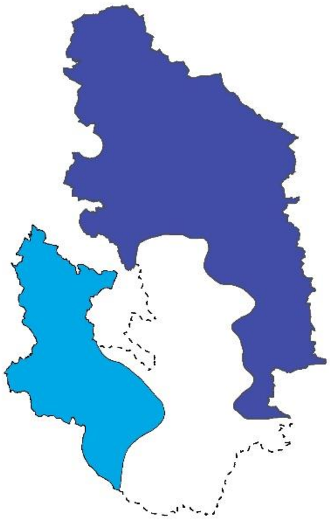
- Establishment of more native trees around riverbanks will assist not only with flood management and water quality but also shade the river and cool the water, although too much shade may be detrimental to aquatic plant life. Increased tree and scrub cover in upland catchments would also be beneficial.
- A greater diversity of habitat surrounding rivers will be beneficial to the invertebrate populations. Variability in shading, as well as wetness of the surrounding habitat is desirable.

Bilberry bumblebee

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:



- Bilberry bumblebee (*Bombus monticola*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The bilberry bumblebee is a distinctive native bee that has a rich orange colour over two thirds of its abdomen. It is found in moorlands areas where bilberry is abundant and where it has access to grassland habitats for other flowering plants such as clover, marsh thistle, and bird's-foot trefoil. A cold-adapted insect, it is one of Britain's rarest bumblebees and in decline across the UK. A locally distinct moorland species, PDNP bilberry bumblebees are on the southern edge of records in England and are found right across the area where habitat is suitable. An exact PDNP population estimate is unknown due to difficulties in recording and quantifying bumblebee populations.

How vulnerable are bilberry bumblebees?

Bilberry bumblebees in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with an unclear but likely poor current condition, and a moderate adaptive capacity.

Habitat changes and a loss of key flowering plants are the biggest threats to this species. Bilberry bumblebees have some scope for adapting to climate change, especially if habitat management focuses on improving floral diversity during nest-building season.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The UK bilberry bumblebee population has declined rapidly in the last few decades. Habitat loss and degradation is thought to be the main cause, as development and mismanagement have resulted in the loss of flowering plants they rely upon. It is likely that populations have also followed this pattern in the PDNP, but due to limited local data and a lack of historical data, this is difficult to assess.

Imported commercial bees bringing in new pathogens and parasites pose a threat to wild bee populations. The current risk level for bilberry bumblebees is unknown but potentially large.

Pesticides are known to impact bumblebees and increased usage has been recognised as one of the causes behind UK bee decline in the last 60 years. For bilberry bumblebees in the PDNP this effect may be reduced due to limited arable cropping and their status as a moorland edge specialists. The real effects of pesticides on PDNP bilberry bumblebee populations is unknown.

Wildfire has probably had a large impact on bilberry bumblebee populations. There were 552 wildfires within the PDNP boundary between 1976 and 2018. Habitat destruction by wildfires on both heather moorland and grassland is difficult to recover from especially when it destroys nests and large areas of foraging ground. Moorland edges are particularly vulnerable as that is where bilberry bumblebees tend to be more abundant.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Queen bees are sensitive to food availability levels when they emerge after hibernation. Mild early springs could see early emergence of bees that have limited food sources. Late frosts could then compromise the bees further as severe cold snaps can cause their food plants to die. With depleted fat reserves, these queen bees are unlikely to survive if their food sources dry up. Loss of queen bumblebees has a detrimental effect that could cause population decline. **[H]** Extreme events such as flooding and drought are likely to affect nests and foraging habitat. Changes to rainfall and temperature could also alter forage plant flowering periods, potentially creating a phenological mismatch between the flowering season and nest building. **[L]** This would mean that new queens might be unable to reach maximum size before hibernation. Fewer bilberries in flower during critical periods may mean that less nectar is available for worker bees, resulting in reduced nest success. On the other hand, better plant growth conditions caused by climate change may increase the productivity and flowering length of key plant species such as bilberry and legumes, giving the bilberry bumblebee an increase in food sources that could improve their condition and increase population sizes. **[L]**

A study of Finnish bumblebees found that queen size before hibernation can determine the sex allocation of colonies (queen/worker/male ratio) ultimately changing the population dynamics and survival rate for future generations. **[M]**

Climate models predict a reduction in suitable climatic conditions for bilberry bumblebees. As a cold adapted species, warmer temperatures are likely to be less suitable for bilberry bumblebees and drive their decline in the PDNP. One study predicts a loss of bees from the southern part of PDNP by 2050, and in a higher emissions scenario complete loss of bilberry bumblebees from all of the PDNP by 2100. **[M]**

Other indirect climate change impacts

Hotter, drier summers put moorland habitat at increased risk of wildfire. Stands of bilberry and heather within this moorland habitat mosaic along with legumes on the edges are likely to be lost if wildfire occurs. This loss of foraging ground along with damage to bumblebee nests may cause bumblebee populations to crash in some areas and decline in others. **[M]**

Invasive or other species interactions

Temperature increases are likely to lead to increased survival of pests and pathogens throughout the year. Pathogens and parasites in bilberry bumblebees may compromise their immune system leaving them vulnerable to other stressors such as habitat change. Loss of bumblebees that are overcome by these stressors will likely lead to population decline in affected areas. **[M]**

Nutrient changes or environmental contamination

Increased plant growth rate due to the increased availability of CO_2 in the atmosphere, may lead to an increase in the use of herbicides in some areas such as waysides and verges. Herbicides may cause a decrease in the floral resource availability that bilberry bumblebees rely upon. Reduced food resources can impact bumblebee fitness and may also cause reduced breeding success. **[M]**

Along with herbicide increases, pesticide usage may also increase as warmer temperatures support large numbers of some insects. These pesticides are likely to penetrate deeper into the dry soil seen in hot, dry summers and may then be taken up by wildflowers absorbing any liquid present. The bilberry bumblebees' exposure to the pesticide may then be two-fold as they are exposed to the initial application as well as the contaminated wildflowers. This can then impair foraging ability and cause population decline. **[L]**

Human behaviour change

Land use choices and management regimes can greatly affect the viability of bilberry bumblebees to survive in any given area. Increased intensity of burning or grazing of moorland habitat is likely to damage large areas of bumblebee foraging habitat. Under-management on the other hand could result in the loss of key food plants as they are outcompeted by scrub or other plant species. A mosaic habitat with a mixture of scrub, woodland and foraging plants can be beneficial if the area is carefully managed to ensure bumblebee food resource and nesting requirements are met. **[L]**

What is the adaptive capacity of bilberry bumblebees? ***[Overall adaptive capacity rating: MODERATE]***

On the southern edge of their range in England, bilberry bumblebees are found on moorland throughout the Dark and South West Peak. They have some opportunity to move north due to reasonable connectivity with other moorlands in the South Pennines. In general, bumblebees are well buffered against fragmentation due to their exceptional foraging skills. They are able to forage across large distances, communicate successful foraging to other workers, and are flexible in their use of food sources. **[M]**

The bilberry bumblebee is a generalist forager that has a strong connection to bilberry and heather. Food availability in the form of bilberry and other key plants such as legumes are important for maintaining the population within the PDNP. Loss of these plants or changes to their flowering season could slow or prevent successful recovery, especially on either side of hibernation. Habitat loss or damage to nests could also interfere with recovery or cause population declines. **[M]**

Environmental land management schemes are available to help restore habitat and improve meadows for pollinators. In Yorkshire, a study on hay meadow restoration demonstrated an increase in bumblebee numbers within restored meadows. Importantly, bilberry bumblebees were seen foraging in these restored meadows which show the bees' ability to adapt and expand their foraging area when habitat is positively managed near existing populations. The Countryside Stewardship Scheme has a Pollinator and Wildlife Package available to farmers which helps encourage positive habitat management such as enhancing food sources for pollinators. In addition, the National Pollinator Strategy sets out ways in which people and organisations can help pollinators, with a focus on expanding food, shelter and nest sites – the basic requirements for bee colonies. **[H]**

Within the PDNP, the National Lottery Heritage Funded 'Pollinating the Peak' project has been underway since 2015. The Bumblebee Conservation Trust set up the project to increase awareness of pollinators and how to help them. Volunteers and citizen scientists also contribute their time to bumblebee surveys in the PDNP, which increases knowledge about the local population, identifying bilberry bumblebee locations and could aid management decisions in the future. However, the project funding is time-limited. Detailed ecology and population estimates are currently unknown. **[M]**

Key adaptation recommendations for bilberry bumblebees:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Continue and build on bumblebee surveys within the PDNP to improve knowledge of local populations.
- Improve habitat management: encourage establishment of bilberry and legumes; limit grazing/mowing during nest-building season; limit pesticide/herbicide use particularly during hot summers.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Assess foraging habitat and identify areas that need improving such as those with a low diversity of food sources and areas where food is unavailable during nest-building season in spring.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

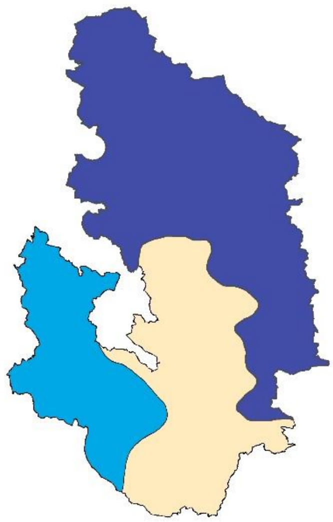
Curlew

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Curlew (*Numenius arquata*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The curlew is the largest of the Britain's wading birds and is easily recognised by its distinctive down curved bill, long legs and brown barred and streaked plumage. The atmospheric bubbling call of this ground-nesting bird is highly evocative of the PDNP bogs and moorland, where curlew currently return each spring to breed. PDNP birds are internationally significant, as an estimated 2% of the UK population is found here, with the UK population being around 25% of the global total.

How vulnerable are curlew?

Curlews in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a low adaptive capacity – despite the currently moderately positive trends in the PDNP compared to the national picture.

Curlew populations in the PDNP are reduced from their historical numbers, but recent data suggests they may be recovering. Climate change is likely to have the greatest impact on curlews in their wintering grounds outside the PDNP through sea level rise and flood defence construction. Within the PDNP, effects on soil invertebrate populations are expected to have the greatest impact. As long-lived and site faithful birds, curlew are not very adaptable. Modelling shows curlew moving north and west out of the PDNP by the end of the century, if they still survive locally. Support from organisations and schemes operating in the PDNP go some way to support their conservation, but more could be done.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

The overall UK curlew population is in rapid decline, showing one of the biggest declines across the bird's worldwide range. In fact, the UK may account for the biggest impact on the global population of any country.

The reasons for the national decline are many and varied. Past drying of peat soils through drainage, burning and wildfires; high rates of human disturbance; destruction of nests through agricultural activity; deterioration of agricultural soils; and a lack of breeding success due to high numbers of generalist predators are all thought to have contributed.

Population trends in the PDNP are less well known and probably vary from site to site. The 2004 Moorland Breeding Bird Survey found an increase in curlew pairs since 1990 across the PDNP. Local data from the Eastern Moors shows that curlew populations are stable or increasing. However, curlew may already be suffering some effects of climate change, as populations have contracted significantly upwards in elevation in recent years. Curlew also appear to be wintering closer to their breeding grounds due to milder winter conditions.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Losses of wintering grounds due to sea level rise may have drastic effects on curlew populations. Most curlew winter on estuarine mud flats. These are at risk of loss to rising seas, compounded by erosion and human developments. Reduction in the height of intertidal patches is predicted to cause reduced survival rates, with a 40 cm loss eliminating survival. Many estuaries are bounded by human developments and sea defences, so habitat will be reduced. Invertebrate availability and curlew feeding time will likely be reduced as a result. This will result in fewer birds returning to the PDNP to breed, and those returning being in worse condition. **[VH]**

In the PDNP, drier summers and extreme events such as droughts may lead to an impenetrable ground surface and invertebrates moving deeper into the soil. This would cause a reduction in invertebrate availability for both adults and chicks, particularly in peatland habitats such as blanket bog or wetter pastures. Drier conditions due to a changing climate or drying of agricultural soils are thought to be the cause of the observed upward shift in curlew altitude. This may continue with drier summers, driving curlew from lowland pastoral sites. Increased annual average temperatures may also have an effect. Cranefly larvae living on the soil surface, which are a major food source for curlew and other moorland waders, are killed off by high temperatures and extreme dry conditions such as those seen in drought. **[M]**

Curlew migration timings may be affected by warmer winters and springs. Similarly, the reproductive cycle of marine invertebrates upon which curlew rely during the winter may be disrupted. Curlews and invertebrate prey may become mismatched, reducing resource availability for overwintering birds. Additionally, it is not known whether these marine invertebrate populations will be able to adapt quickly enough to changing conditions to survive in some locations, further reducing availability at some wintering sites. These effects combined would mean reduced curlew fitness upon migration, and so fewer birds surviving the return journey. However, increasing numbers of curlews are wintering close to or at their breeding grounds, meaning that PDNP curlews may decrease migration as conditions change. **[M]**

Human behaviour change

Climate change is likely to lead to increased construction to combat its effects, from renewable energy sources such as wind turbines to sea defences to combat sea level rise. The effect of upland wind farms on breeding bird densities is disputed, and the PDNP’s status as a National Park will be likely to help protect PDNP curlew populations, though migration routes may be affected **[L]**

However, there is limited protection for many wintering grounds. An increase in offshore or nearshore wind could reduce curlew numbers. Tidal barrage construction to generate renewable energy may reduce curlew density significantly, though the effect is not well studied. Habitat may also be lost to hard flood defences, which become a barrier to movement as sea level rises. Managed realignment of the sea could put pressure on wintering curlew to adapt to habitat changes, though may provide opportunities through habitat creation. **[H]**

Inland, upland forest establishment may too prove damaging to curlew populations. Some curlew declines have been strongly associated with an increase in surrounding woodland. Woodland establishment for carbon offsetting and flood management could affect PDNP curlew populations. **[H]**

An increase in visitors due to hotter drier summer conditions may increase disturbance. Curlews are known to be highly sensitive and visitor pressure has been associated with the absence of breeding curlew on South Pennine uplands. Land use changes will also affect curlew populations. Some land may be abandoned as ground conditions change leading to afforestation, removing curlew habitat. **[H]**

Changes to the economics of grouse moor management due to altered moorland conditions may have negative effects on curlew. Changes in the climatic conditions of heather moorland could lead to some sites being abandoned as uneconomic, while intensive management may increase on others to offset these changes. Loss of predator control would have a negative effect on curlew nesting success, at least in the short term, due to predation. Conversely, an increase in burning management could cause a reduction in curlew populations. **[L]**

Invasive or other species interactions

Increased annual average temperatures may have diverse negative effects on curlew through their interactions with other species. Warmer winters could raise survival rates of generalist predators such as foxes and carrion crows, leading to increased nest predation in the spring. Higher temperatures may also increase the prevalence of parasites on curlew. Although parasite effects on the host are not well understood, a greater parasite load is likely to be detrimental to curlew fitness and fecundity. Finally, warmer spring temperatures can promote green algae growth in estuarine wintering grounds. Algal mats negatively affect marine invertebrate abundance, reducing food availability for wintering curlew and lowering their migration fitness. **[L]**

An increase in atmospheric carbon dioxide, combined with increased nitrogen deposition from winter rainfall may act to increase plant growth rates. This could negatively affect curlew nesting, as an increase in sward height would reduce visibility, an important feature in curlew nest choice. Young birds choosing a nest site would have more limited options, and those birds already faithful to a nest site would be more vulnerable to predation. Higher plant growth rates may also encourage scrub encroachment in low grazing areas, reducing curlew habitat. **[M]**

Nutrient changes or environmental contamination

Changes in annual precipitation cycles could negatively affect curlews through altered nutrient status of their habitat. Wetter winters and drier summers may affect wetter sites such as bogs and wet flushes that are preferred for curlew feeding. Higher flows in winter may cause flushing of nutrients from the system. Altered nutrient status can change invertebrate abundance and community composition, limiting food resource for curlew. **[L]**

Sedimentation or erosion

An increase in the frequency and severity of storms and droughts may act to increase erosion on curlew habitat. As many curlew nest on the fragile peatlands of the PDNP, this could have severe consequences. Further drying and loss of peat would reduce available habitat and cause deterioration in the condition of existing habitat. Invertebrate availability declines relative to peat condition, reducing fitness of curlew on degraded habitats. **[L]**

Other indirect climate change impacts

Hotter drier spring and summer conditions may increase curlew losses to wildfire. Increased frequency and severity of wildfire would increase nesting losses in ground nesting birds and cause habitat loss on open moorland. Because curlew are site faithful, re-nesting after large-scale wildfires may be unlikely, though post-restoration habitat may become available. **[L]**

What is the adaptive capacity of curlew? ***[Overall adaptive capacity rating: LOW]***

Suitable curlew habitat is increasingly fragmented within the PDNP, with large areas of unsuitable moorland and pastureland separating good habitat. Curlew are generally faithful to a nesting site, and young tend to nest near their hatching location, so population expansion and movement is slow. There are few other barriers to movement, so curlew populations are able to adapt to changing conditions if they are not too rapid. Modelling shows curlew moving north and west out of the PDNP by the end of the century, if they still survive locally. **[H]**

Curlew can recover from significant losses if the conditions are right. Dispersal is relatively good albeit slow, so adjacent populations can replace those lost. However, their behaviour is not likely to be flexible, and their evolutionary potential to adapt is low. This is due to their long lifespan with a slow maturity to breeding age, combined with small clutch sizes. **[M]** Their status as a specialist with specific requirements for both summer breeding and wintering conditions may limit their adaptability. **[VH]**

Some money is available for curlew conservation in the PDNP. Many agri-environment schemes focus on farmland waders including curlew. These schemes have been shown to be effective for farmland birds across Europe, or at worst not harmful. However, it is questionable whether these schemes are effectively implemented, and there is uncertainty over the future due to exit from the Common Agricultural Policy (CAP) and other changes in land policy. **[L]**

Institutional support could assist curlew climate change resilience. Projects such as the RSPB Curlew Recovery Programme and the South West Peak Partnership Working for Waders aim to implement and assess management interventions to promote curlew recovery, and therefore climate change resilience. However, serious management interventions on land not specifically used for nature conservation are more difficult to achieve. Much of curlew habitat in the PDNP is covered by Site of Special Scientific Interest (SSSI) or Special Area of Conservation (SAC) designation, with curlew mentioned as a reason for citation in the Dark Peak SSSI. These designations have been shown to have a positive correlation with curlew densities. Curlew are also a red listed species in the UK, giving them some conservation priority. **[M]**

Management for curlew is reasonably well known. Moorland rewetting is being implemented across the Dark and South West Peak, and can improve curlew habitat by increasing vegetation heterogeneity and abundance of their invertebrate prey. However, drain blockage benefits fly larvae most, which form a lower proportion of curlew diet than in other waders. As a result, curlew may not benefit from rewetting as much as other species. More research is required to understand which management techniques are the most effective and how curlew interact with their habitat, climate, and other species. **[M]**

Key adaptation recommendations for curlew:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Create or back experiments to test the effectiveness of current and potential management techniques.
- Improve curlew habitat and increase connectivity through management.
- Ensure silage cutting is delayed until after chicks have left the nest.
- Cease the ploughing of fields and reduce chemical inputs to improve soil invertebrate populations.
- Maintaining sward lengths above minimum can reduce predation risk and can mean less predator control is needed.
- Rush management should be planned with the needs of different species in mind, some suitable areas of long rushes should be left intact.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Further study is needed to track how productivity and breeding success are changing with climate. Recording of clutch sizes at nest can help.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Wetland restoration should be a priority. This is both through upland rewetting and lowland drain blocking.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Adapt land use for future conditions

These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

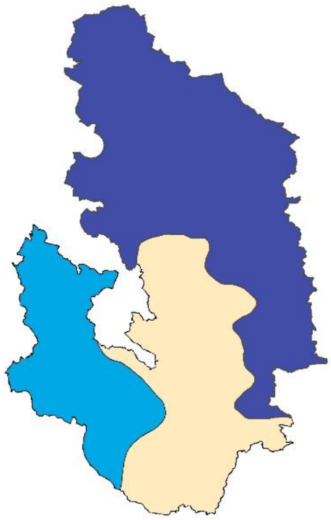
- Reduction of soil compaction will reduce surface drying and increase habitat suitability for curlew.
- Reduce high grazing levels and avoid intensification of farming methods.

Dipper

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Dipper (*Cinclus cinclus*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The dipper is a medium sized dark coloured bird, similar in appearance to a thrush but with a large white patch on its front. It is unique among British passerines for its ability to walk and swim underwater to catch its food. It can be found along streams in the PDNP, especially in the White Peak, where it fishes for invertebrate prey, bobbing its body and cocking its tail. Dipper are a charismatic UK native bird, a pleasure to see along shady PDNP streams, and a valuable indicator of water quality and ecosystem health.

How vulnerable are dippers?

Dipper in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor but potentially recovering current condition, and a moderate adaptive capacity.

The population size in the PDNP is not well known, but national trends show a decline in dipper populations. The largest climate change impacts on dipper will be those that affect their invertebrate prey. Increased water acidity and excess nitrogen will therefore be likely to have the greatest effect. Changes to annual flow cycles will likely also have an impact on dipper populations. The dipper itself is only moderately adaptable, having specific habitat requirements and low dispersal, but could benefit from economic and institutional support. This will mostly be indirect, through initiatives to improve water quality and natural flood management.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Dipper populations are in decline across the UK, with a fluctuating population but an overall downward trend over the last 30 years, especially in England. Trends in the PDNP have appeared generally better than the national average, but recent comprehensive data is not available for this species. Dipper in the PDNP are almost at the eastern edge of their range; they are not currently found east of a line from the Humber estuary to the Isle of Wight. Climate change is thought to be currently benefitting dippers due to increased winter survival. Previously suffering from severe heavy metal pollution of streams, dipper clutch sizes and fledgling success has been steadily increasing in recent years. That the overall UK population is still declining implies less obvious influences are in action on the dipper. Predation may be one factor in the PDNP. The invasive American mink has wiped out the dipper in some areas of Shropshire, and is present here. In areas near housing, domestic predators such as the cat are likely to be a significant factor.

Dipper are highly sensitive to poor water quality, especially in the form of heavy metal pollution and acidity. This is probably due to a reduction in the abundance of their invertebrate prey. The acidity of streams in the PDNP is possibly a significant limiting factor in dipper population recovery, as well as heavy metal pollution from historically contaminated peat. Agrochemical runoff is probably also significant: nitrogen fertilisers, pesticides, and herbicides have the largest effect on the invertebrate prey of the dipper. Inputs from wastewater facilities including pharmaceuticals may also negatively affect freshwater invertebrate populations.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Changes in annual precipitation cycles may affect dipper populations through changes in river flows. High flow can cause rivers to be less suitable for dipper, with foraging opportunity decreased, and prey visibility reduced. Lower summer flows may reduce invertebrate populations and increase pollutant concentration. Ephemeral rivers in the White Peak could also vanish for longer periods, reducing dipper habitat. Dipper breeding and phenology is thought to be primarily controlled by river flows. This reduction in suitability over larger parts of the year is likely to decrease breeding success. **[H]** Flooding and drought may also have a direct effect on adult mortality, but this is less well studied. **[L]**

Increased atmospheric carbon dioxide may have deleterious effects on dipper populations by increasing stream acidity. Increased atmospheric carbon dioxide will mean more is dissolved into watercourses as carbonic acid. This would decrease the abundance and change the community composition of dipper’s invertebrate prey, causing them to spend more time foraging. **[M]**

Although dipper currently appear to benefit from higher annual average temperatures, this benefit may be cancelled out by declines in invertebrate prey. Modelling has shown that temperature rise could be disastrous for freshwater invertebrate populations, with a potential 21% decline in abundance for every 1^{o}C rise in temperature. This would represent a drastic decrease in food availability for dipper, resulting in reduced survival and breeding success. This could offset any gains in dipper populations caused by decreased winter mortality. Dipper may therefore move northwards and upstream if possible. Dipper are on the southeastern edge of their range in the PDNP, so this may result in losses in some areas. Temperature changes may also affect the phenology of some prey species such as the mayfly, resulting in reduced food availability at crucial times of the year. **[M]**

Human behaviour change

Increased water abstraction from rivers in the PDNP during drier summers is likely to further impact river flows. Loss of species that favour faster currents and changes to river channel patterns may reduce dipper populations. Additionally, if flood defences are built to counter high winter flows they may have a similar effect by changing the course of the river. Hard flood defences would also represent a barrier to the movement of dipper prey, and any increase in dredging for flood management could reduce their populations. **[H]** Some smaller streams may also be used for micro-hydroelectric projects to reduce dependence on carbon based power generation, causing channel diversion and modification. **[L]**

Dipper could benefit from changes in human behaviour as PDNP land use changes. Sheep farming has been shown to affect dipper populations negatively, likely in large part due to sheep dip entering watercourses and killing off invertebrate prey. Increased broadleaved woodland after sheep removal has also been shown to be beneficial. If changes in climate mean stocking densities are lowered, this could cause an increase in dipper numbers in nearby streams. On the other hand, if arable land increases near waterways, then increased sediment, nutrients and agri-chemicals in the water are likely to have negative effects. Hotter summers may also cause an increase in visitor numbers to water bodies in the PDNP, increasing disturbance of the dipper. **[M]**

Nutrient changes or environmental contamination

Warmer conditions increase nitrogen flux in the soil due to higher soil respiration rates, which can be transported by runoff into watercourses. Higher nitrogen availability is likely to increase the frequency of algal blooms, leading to eutrophication. This effect may be compounded by higher water temperatures, as dissolved oxygen capacity reduces. Combined, higher temperatures may lead to larger and more common areas of anoxia within streams, killing off invertebrate prey and thereby reducing suitability for dippers. **[M]**

Higher water temperatures may also decrease the capacity of upland streams to hold dissolved organic carbon and oxygen. Lower 'brownification' of water from dissolved carbon improves dipper foraging ability, but lower dissolved carbon and oxygen may impact invertebrate populations. This could make some streams less suitable habitat for dipper as their preferred prey is lost or reduced in abundance. **[M]** Greater runoff from PDNP peatlands could counter this effect to some degree by introducing more peat into the watercourse, acting as a source of carbon that can be dissolved as carbonic acid. **[L]**

Invasive or other species interactions

Increased annual average temperatures may cause an increase in invasive species in riparian habitats. Non-native species such as Himalayan balsam can crowd out other species on riverbanks, leaving bare ground when they die back in winter. This causes increased erosion and siltation of riparian habitats, as well as changes in water chemistry. These effects may act to reduce the suitability of some habitat for dipper. **[M]** An increase in storm events may magnify this effect by opening up bare ground and increasing disturbance on riverbanks, providing opportunities for invasive species to move in. **[L]**

Sedimentation or erosion

An increase in the frequency and severity of wildfires could increase erosion material entering the watercourse, especially in peatlands. This would lead to intense events of siltation and changes in dissolved organic carbon, reducing the abundance of freshwater invertebrates and changing community composition. The overall effect would depend on how quickly these systems can recover from these events, but dippers may be affected at least in the short term. Erosion may also be increased generally due to the increased runoff associated with greater winter rainfall and more frequent summer storm events. Siltation would therefore increase in watercourses near agricultural lands and roads, and dissolved organic carbon levels in those near peatlands. **[L]**

What is the adaptive capacity of dippers? ***[Overall adaptive capacity rating: MODERATE]***

Dipper are associated only with riparian habitats within the PDNP, meaning that habitat connectivity is generally only within river systems. Dipper chicks can disperse to other river systems, but generally move less than 10 km from their natal site. Habitat is more fragmented in the WP, with vanishing rivers removing some areas of habitat for part of the year. **[M]** Dipper also have specific habitat requirements, needing high flow variability and areas of deeper water for foraging. Expansion into new habitats is therefore dependent on suitable flow patterns being present, and new flow regimes will be needed to allow dipper populations to move back into some areas where they have been lost. These requirements mean that the dipper is less adaptable to change. **[VH]**

Some funding is available for dipper conservation, though mostly through conservation of suitable habitat. Works to improve water quality at a catchment level are ongoing in many parts of the PDNP, which will likely benefit dipper populations by increasing invertebrate prey availability. Natural flood management projects would also benefit dipper, as riparian broadleaved woodland and flow variability have been shown to correlate with increased dipper populations. However, the complexity of current environmental land management schemes means that there is a poor incentive for landowners to take them up. Withdrawal from the EU Common Agricultural Policy means that there is now an opportunity to change the way that ecosystem services are valued. **[M]**

Some institutional support is available for dipper conservation. The European Union Water Framework Directive provides a regulatory process for monitoring and improving water quality, but only on main rivers. As dipper usually live on smaller streams, this of value indirectly. Organisations are working within the PDNP to improve water quality and improve watercourse health, benefitting the dipper therefore. Some dipper habitat is protected under Site of Special Scientific Interest (SSSI) designation, providing some protection from degradation and exploitation. The dipper is also an amber listed bird in the UK. **[M]**

Management for dippers is relatively well known, being strongly related to water quality and flow variability. Improving water quality is already a priority in the PDNP, with legacy heavy metal pollution and peat sediment in water courses both undergoing reductions. However, dipper populations are still declining, suggesting that gaps in management knowledge still exist. **[M]**

Key adaptation recommendations for dippers:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Minimise agricultural inputs, especially slurry, fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.
- Increased natural flood management measures will benefit dipper. This includes upland woody damming, broadleaf woodland establishment, and natural scrub regeneration.
- Hydroelectric power schemes have the potential to be very harmful to dipper and other riparian species. Natural processes within river systems are key to the adaptive capacity of the system. Developments should only be approved if they interfere minimally with the natural course of the river.
- Dipper should be considered when building structures to regulate flow. Construction should be limited during dipper breeding season.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

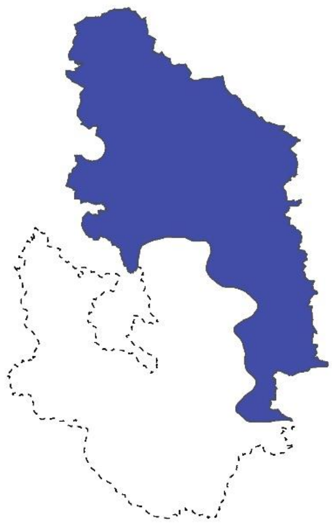
- Conifer plantations beside rivers are detrimental to dipper populations. Streamside conifers should be phased out and replaced with native broadleaf wherever possible.
- Improve variation in streams: riffles, rocks, and boulders can create variable flow and deeper sections. This creates better foraging habitat.

Dunlin

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Dunlin (*Calidris alpina*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The dunlin is a small wading bird, which is a rare breeder on moorland in the Dark Peak. They are much smaller than a snipe or curlew, but still have the distinctive long bill of a wader. Dunlin nest in scrapes on moorland during the spring and summer, leaving for the coast in the autumn where they gather in large flocks. While in the PDNP dunlin are in their breeding plumage: a rusty-brown back with white underparts, and a black patch on the belly. They mainly feed on soil invertebrates by probing soft ground, and prefer wet ground for this reason.

How vulnerable are dunlin?

Dunlin in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a moderately unfavourable current condition and a low adaptive capacity.

Dunlin populations in the PDNP have been in decline historically, but recent increases in some areas are a positive sign for the population as a whole. Dunlin are a relatively mobile species, and rising temperatures are likely to cause breeding populations to move northwards and be lost from the PDNP. Further loss of blanket bog functionality may also disadvantage dunlin populations due to reductions in their invertebrate prey. Blanket bog restoration has proven very beneficial for dunlin, but is may not be enough to retain breeding populations in the future.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

Dunlin appear to have a small but relatively stable breeding population in the Dark Peak. The 2004 Moorland Breeding Bird Survey showed a decline in breeding dunlin, but local data now shows increases in some areas. Moorland rewetting efforts appear to have assisted recovery and population expansion is possible when degraded habitat is restored. The PDNP dunlin population is at the southern edge of its modelled breeding range in England. However, it is worth noting that a small breeding population on Dartmoor persists much further south and outside of this modelled range.

Upland moorland in the PDNP is still heavily polluted as a legacy of the industrial revolution. Heavy metals are present and pH levels are very low. This will reduce soil invertebrate activity and abundance, reducing food resources for dunlin and other waders.

Extensive erosion of peatlands in the PDNP has severely reduced habitat suitability for dunlin. Drainage and exposure of peat has led to gullying and drying out of soils, reducing invertebrate populations such as cranefly larvae. Moorland rewetting efforts have gone some way to counter this in recent years, but much work remains to be done.

Wildfire has likely removed large areas of dunlin habitat periodically, slowing population recovery. In the degraded and well-visited uplands of the PDNP wildfire is common. Fire may have destroyed nests and prevented re-nesting by clearing large areas.

Visitor disturbance will have some impact, but this effect is likely to be restricted to the most popular sites and near footpaths. High visitor pressure has been shown to affect upland waders in the most heavily visited areas, but some studies have shown no significant effects on breeding bird populations in the PDNP. Dunlin nesting at popular sites such as Dove Stone will be more at risk from disturbance.

As ground nesting birds, dunlin are likely impacted by generalist predators such as red fox and carrion crow which will take young birds at the nest, and possibly even adult birds due to their small size.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Increased average annual temperatures may have mixed effects on dunlin populations. The number of reported dunlin fatalities have been found to increase during severe winters, so warmer winters may lead to greater dunlin survival at their wintering grounds. However, rising temperatures may move suitable habitat space northwards over the next century. Dark Peak dunlin are on the southern edge of the Pennine breeding population, so local populations will be some of the first to feel this effect. Models show that even under mild warming scenarios, breeding dunlin will likely be lost from most of England, becoming restricted to the Scottish highlands. Therefore, any population gains from warming winters may not affect the PDNP as dunlin move north out of the area and are lost. **[VH]**

Drier summers and increased drought frequency may cause changes in dunlin habitat. Much of the degraded bog in the PDNP is already functionally dry heath, with drought tolerant species such as heather dominating. Drier conditions may exacerbate this change and make rewetting efforts more difficult. If habitats become drier, soil invertebrate populations will decline and foraging will become more difficult in harder ground. Dunlin breeding success would therefore decline as food resource availability decreases. **[H]**

Greater weather extremes may contribute to habitat damage and degradation. Cracking and shrinkage of peat during more frequent drought is likely to make degraded peatlands more susceptible to erosion. Erosion will be greatest during storm events, increasing gully size and forming new gullies and peat pipes. As a result, damage to dunlin nesting and feeding habitat is likely to increase, reducing dunlin breeding success. **[H]**

Human behaviour change

As weather conditions become more variable, intensification of land management may be used to counter these effects. While it is impossible to predict the human response to climate change, any intensification of grazing pressure or rotational burning regimes would negatively affect dunlin populations. High stocking levels would increase disturbance and decrease habitat suitability, and burning management can remove habitat. Dunlin breeding on agricultural land and grouse moors could therefore have reduced breeding success as the remaining wet areas are lost. **[H]**

Sea level rise may cause an increase in construction of coastal flood defences and coastal realignment in dunlin wintering grounds. This could remove or squeeze the coastal habitat available to dunlin, and increase competition for resources. However, some coastal realignment may increase the size of mudflats opening up new opportunities for winter sites. Winter survival rates may be reduced overall, along with poorer body condition upon return to the PDNP. Dunlin breeding success may decrease as a result. **[H]**

Hotter drier summer conditions may cause a rise in visitor numbers in the PDNP. More traffic on footpaths, a greater numbers of dogs and walkers crossing open moorland would increase disturbance to nesting birds. The result of such disturbance is unclear, but it is a reasonable assumption that it would negatively affect populations to some degree. **[M]**

As climate change advances, carbon capture efforts are likely to increase. In the PDNP, bog restoration and rewetting will probably form a large part of this effort, improving and increasing dunlin habitat. As habitats become wetter, prey abundance and accessibility and therefore dunlin breeding success will increase. **[M]** Bog restoration as a natural flood management method may increase to counter more frequent and severe flooding. Dunlin habitat suitability and therefore breeding success would therefore increase, at least temporarily until the lack of rainfall or drying outweighs the benefits of the rewetting. **[L]**

Other indirect climate change impacts

Increased annual average temperatures may have negative effects on dunlin populations through interactions with their invertebrate prey. Invertebrate productivity increases with temperature to a point, but begins to decline as temperatures rise further and soils dry out. Although dunlin may benefit from temperature rises at first, they could later decline as their prey becomes less available. Several drought years in a row could negatively affect breeding bird fledging success if invertebrate numbers become very low. **[H]**

Higher temperatures and drier ground conditions may make wildfire more frequent and severe in the PDNP. This could result from accidental ignition or from managed burns running out of control. Degraded bog habitats that are currently dry heather dominated moorland are particularly at risk. Further increases in wildfire would mean more nests lost and less nesting habitat available, reducing dunlin breeding success. **[H]**

Nutrient changes or environmental contamination

Greater winter rainfall and frequency of summer storm events may increase episodic nitrogen deposition. This could disadvantage *Sphagnum* mosses, especially in combination with summer droughts. *Sphagnum* mosses would be disadvantaged directly through inhibition of their growth and indirectly by removing their competitive advantage over vascular plants. *Sphagnum* mosses being lost from bog habitat would result in reduced peat accumulation and drying out of peat. Dunlin prey would be less abundant and accessible, leading to reduced dunlin fitness and breeding success. **[H]**

Changes in annual precipitation cycles could change the nutrient availability in bog ecosystems. A greater hydrological input in winter may cause flushing of the system, preventing already scarce nutrient inputs from entering the system. Conversely, reduced input in summer may increase nutrient availability in some areas through concentration. Such changes in nutrient cycling may negatively affect the bog ecosystem, potentially reducing populations of invertebrate prey. Dunlin would have reduced foraging success and therefore breeding success. **[L]**

Sedimentation or erosion

Drier summer conditions could increase erosion of degraded peatlands through drying of peat. As winter rainfall and summer storm events are likely to intensify, erosion of peat by surface water would also increase. Greater gullying could occur, further draining the surrounding area. This process could accelerate or restart degradation in moorland undergoing restoration, reducing its suitability as dunlin habitat. Dunlin habitat area and breeding success would therefore be reduced. **[H]**

Invasive or other species interactions

Multiple climate change related effects may act to change the vegetation community of dunlin habitat. Changes in nutrient availability may lead to a greater plant growth rate in some areas. Nitrogen deposition events could increase due to greater winter rainfall and summer storm frequency, causing faster growth rates in some species.

Increased average temperatures could also contribute by lengthening the growing season, increasing sward height and scrub growth rate. Invasive plant species may colonise larger areas. Dunlin nest sites require good visibility over the surrounding area, meaning there may be reduced nesting opportunities for dunlin. **[M]**

What is the adaptive capacity of dunlin? ***[Overall adaptive capacity rating: LOW]***

Dunlin are a mobile species with few barriers to population spread and movement. However, there is no population to the south or east to replace the PDNP population as suitable climate space moves northwards and westwards. Dunlin are likely to react to rising temperatures by moving northwards beyond the PDNP boundary, meaning their loss from the area. **[H]**

Some funding may be available for dunlin conservation in the form of environmental land management schemes. Such schemes would be beneficial through improvement of habitat rather than specific interventions for dunlin conservation. The UK's exit from the European Union presents opportunities to reform agricultural subsidies to benefit nature, but the future is very uncertain. **[L]**

Dunlin are protected to some degree by designation. The South Pennines Special Protection Area (SPA) is designated for birds including the dunlin, and much of dunlin territory lies inside the Dark Peak Site of Special Scientific Interest (SSSI). Dunlin are an amber listed bird in the UK and so are of some conservation importance. Organisations working within the PDNP are working towards dunlin population recovery, with the RSPB and United Utilities Dove Stone Estate being a flagship for dunlin conservation within the PDNP. **[M]**

Some knowledge of management interventions for dunlin exists within the PDNP, mostly being focused on moorland revegetation and rewetting. Studies at Dove Stone have shown this to be an effective technique for increasing populations of dunlin and other waders. Management techniques outside of habitat creation and improvement are less well known. **[H]**

The dunlin as a species does not appear to have a large capacity to adapt. UK dunlin are reliant on wet bogs with pool complexes for breeding habitat, and suitable coastal habitat for wintering. The Dartmoor dunlin population indicates that dunlin may be able to live outside of what is assumed suitable climatic space, but otherwise dunlin show little evidence of behavioural plasticity. **[L]**

Key adaptation recommendations for dunlin:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Rewetting of moorland and blanket bog restoration is the most beneficial intervention for dunlin. Implementation of this management will benefit other waders and have associated benefits of carbon storage and water storage.
- Moorland gully and grip blocking for creation of bog pools creates good feeding habitat for dunlin.
- Upland conifer plantations remove dunlin habitat and should be phased out from areas where they are thought to be limiting populations.
- Partnership with coastal conservation organisations will be the best way to create an integrated management plan, as dunlin may winter in other areas.
- Reducing the number of sheep and therefore lambs may also reduce pressure from generalist predators. Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. The increase in Dunlin at RSPB Dove Stone has not included predator control, so good quality habitat can counterbalance the effects of predation. Research is needed to determine if a more natural system would be a better option for the future.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

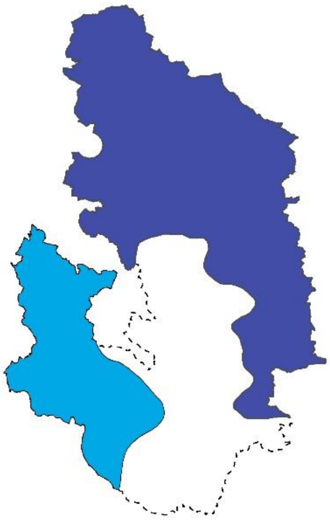
- Ensure dunlin habitat has well marked and maintained footpaths to prevent encroachment of visitors onto breeding areas.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Golden plover

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Golden plover (*Pluvialis apricaria*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The golden plover is a medium sized, short-billed wading bird with striking golden and black breeding plumage. Its mournful whistling call can be heard on PDNP moorland where it currently returns to breed each spring. The South Pennine Moors Special Protection Area (SPA) was designated partly because of the European importance of its breeding golden plover population. Britain holds the vast majority of the European breeding population, of which the South Pennines represent over 3%. In addition, PDNP breeding populations are some of the most southerly in the world.

How vulnerable are golden plover?

Golden plover in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a variable current condition, and a moderate adaptive capacity.

Golden plover populations in the PDNP show signs of recovery from historic decline, increasing in recent years. The greatest risk to PDNP golden plover populations is loss of suitable habitat as temperatures rise. Populations will likely move northwards out of the park boundary over the next century. Effects on coastal wintering grounds will likely also be significant, with sea level rise removing habitat and causing greater construction of sea defences. Golden plover are not very adaptable, as a moorland specialist with limited space within the PDNP to move with changing conditions. However, support from conservation organisations and environmental stewardship schemes should go some way to improving their resilience.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Golden plover populations appear to be recovering across the UK, having again reached 1994 population levels after a 20% decline in recent years. The PDNP population trend is less well known, with a slight decline shown by the 2004 Moorland Breeding Bird Survey, but is likely to be highly site specific. The greatest abundance has generally been found to the north of the Longdendale valley. However, there has been a loss of the species from generally drier, lower altitude bogs on the Eastern Peak District Moors and from the lower altitude fragmented bogs in the South West Peak. The historic extensive degradation of PDNP peatlands since the industrial revolution means there are likely to be fewer breeding pairs present than could potentially be supported if the habitat was in good condition. Disturbance, wildfire, high numbers of sheep and intensification of in-bye land have probably all played a role in keeping numbers below their potential. However, a significant increase in numbers and productivity of golden plovers at RSPB Dove Stone has been observed. This followed peatland revegetation and rewetting work, with numbers almost doubling between 2004 and 2017.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

The PDNP is an important breeding ground for golden plover. In addition, climate change effects at their mainly coastal wintering grounds and other areas they use on passage may also have significant effects on this species. Climate change is likely to have detrimental impacts on golden plover.

Direct impacts of climate change

Climate change modelling has shown that golden plover may be lost from much of England as temperatures rise. Golden plover distribution is expected to contract to the north Pennines and Scottish Highlands. The loss of golden plover on the Eastern Peak District moors may be the first evidence of this shift: populations may have moved as suitable climate shifted northwards and upwards in altitude. Over the next century, the entire PDNP is likely to become unsuitable habitat for golden plover, and populations will move north. **[VH]**

Hotter, drier summers and increased drought events may have a significant impact on the invertebrates on which golden plover feed. Golden plover rely on crane fly as a food source. High summer temperatures can kill larvae in the peat surface, reducing numbers the following year. Pools may also dry up also reducing crane fly abundance. Reduced craneflies will reduce breeding success. A phenological mismatch may also be created between golden plover lay dates and crane fly emergence dates that will reduce the likelihood that early breeding attempts are successful. **[VH]** Modelling indicates that breeding success in South Pennine populations could be reduced by around 11% as a result.

Milder winters and warmer springs have been shown by various studies to have positive effects on winter survival, productivity and chick growth – and this may be the case in the PDNP at least in the short term. **[M]**

Human behaviour change

Rising sea levels and more frequent and severe storm events at the coast are likely to increase the construction of new hard flood defences. The construction of new barriers or squeezing of habitat would result in a loss of foraging sites and roosting locations, although in some areas it could also see the creation of some new mudflat habitat. This could reduce winter survival rates and decrease body condition at the start of the breeding season for some birds. On the other hand, these birds may opt to utilise lowland fields more, as these are rich in earthworms and soil invertebrates. **[H]**

An increase in annual average temperatures and changed precipitation pattern have the potential to cause changes in agricultural economics in the PDNP and surrounding areas. Grass leys and in-bye land appear to be an important resource for birds on passage. Conversion of such areas to different uses could have a significant detrimental effect. **[L]**

Within the PDNP, hotter and drier summers are likely to increase further the currently high number of recreational users in the uplands. Golden plover have been shown to be sensitive to disturbance, especially where visitor pressure is high, resulting in a reduction in reproductive success. **[L]**

Climate change mitigation measures could be detrimental to golden plover. **[L]** An increase in windfarm construction or the afforestation of the uplands would be likely to result in a loss of habitat and a decline in numbers. However, the likelihood of these outcomes within the PDNP currently appears to be low.

Sedimentation or erosion

Erosion is likely to increase on some golden plover wintering grounds due to sea level rise. Loss of sediment from mudflats and sandbanks would reduce feeding area for wintering golden plover. This sediment may then be redeposited, changing the substrate composition and reducing invertebrate populations. Less available food resource and greater competition for habitat could reduce golden plover winter survival. **[H]**

Greater weather extremes may increase erosion on golden plover breeding habitat. More frequent drought could increase cracking and shrinkage of peat, especially where it is exposed. Higher winter rainfall and an increase in summer storm events could increase erosion, especially on peat soils where vegetation cover is low and drought effects are greater. As PDNP moorland is already highly degraded, this could further reduce habitat area and suitability for golden plover. **[L]**

Invasive or other species interactions

Vegetation changes may decrease the suitability of golden plover habitat. A greater carbon availability due to increased atmospheric carbon dioxide levels combined with higher temperatures may increase plant growth rates in some areas. A generally increased sward would be detrimental to golden plover, as a short sward is preferred nesting and feeding habitat. Scrub encroachment may also occur, reducing habitat suitability. **[M]**

Increased annual average temperatures may increase the wintering survival of generalist predators such as red fox and carrion crow. Increased predator numbers would reduce the reproductive success of golden plover due to nest and chick predation. **[L]**

Changes in the PDNP climate may cause some grouse moor management to change in intensity. Changes to predator control may affect plovers. However, it is unclear what impact this would have. Though predator control can be beneficial for waders, projects such as the Dove Stone Partnership have shown that golden plover populations can grow without it. In some cases, predator control may even be sustaining inflated predator numbers. **[L]**

Nutrient changes or environmental contamination

Changes in annual precipitation cycles may affect nutrient availability in golden plover habitat. Greater water input in winter may cause flushing, reducing nutrient availability, while lesser input in summer may increase nutrient concentration in the remaining water. The functioning of habitats would be impacted, especially blanket bog. Invertebrate availability may be reduced. **[L]**

Other indirect climate change impacts

Drier summer conditions and an increase in the frequency of drought may increase the occurrence of wildfire in the PDNP. This risk could be exacerbated by increased vegetation growth rate. Wildfire will be more significant on drier heather moorland, which currently hosts much of the PDNP golden plover population. **[L]**

What is the adaptive capacity of golden plover? ***[Overall adaptive capacity rating: MODERATE]***

Despite being part of the large South Pennines population, golden plover in the PDNP face significant barriers to adaptation. Being at the south-eastern edge of their UK range, they have few neighbouring birds to bolster or replace lost populations. Crucially, as suitable breeding conditions move northwards with rising temperatures, golden plover are likely to respond by moving northwards out of the PDNP boundary. Local extinction within the PNDP is a strong possibility, as the birds either move to new habitat further afield or die out in unsuitable habitat. **[H]**

Golden plover show some evidence of behavioural plasticity, which may increase their climate change resilience. Golden plover chicks are able to move considerable distances to locate areas of greater prey availability, allowing them to adapt to changing conditions. However, as a moorland specialist, they are unlikely to be able to adapt sufficiently as habitats change. **[M]**

Some economic resource is available which could help golden plover conservation in the PDNP. Most of the in-bye land used by golden plover near the Peak District Moors SPA has been identified and is already under environmental stewardship. However, the future effectiveness and implementation of such stewardship is currently unclear. **[L]**

Institutional support may assist golden plover resilience. Recent management of the uplands has had a greater focus on rewetting and revegetation by conservation organisations. Such interventions are likely to be beneficial for golden plover and increase the resilience of the habitats they depend on. PDNP golden plover habitat also lies within the South Pennines SPA, providing some protection. **[M]**

Golden plover are a well-studied species, so adaptation measures can be made with reasonable confidence. Around 21% of the British breeding population occur within SPAs, with reviews conducted semi-regularly on the status of the species within. These reviews specifically investigate climate change impacts, meaning golden plover responses to climate change and possible interventions can be well informed. **[M]**

Key adaptation recommendations for golden plover:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Blocking of drainage and rewetting of bogs and moors will increase the resilience of golden plover habitat to climate change.
- In-bye land can be good habitat for golden plover. Good management will allow golden plover and other waders to make use of these resources without sacrificing productivity.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Well maintained footpaths across the moors will reduce disturbance of golden plover and other ground nesting birds.
- Conifer plantations have historically reduced golden plover habitat. Establishment of new plantations should be discouraged and existing plantations removed where they have an impact on golden plovers.
- Partnership with coastal conservation organisations and other organisations who manage winter feeding grounds to provide integrated management is a better strategy than breeding ground only methods.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

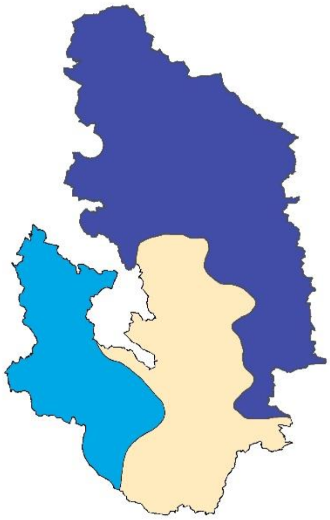
Great crested newt

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Great crested newt (*Triturus cristatus*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The great crested newt is the UK's largest newt. It is easily recognised by its distinctive bright orange underside covered in irregular black blotches and the large crest along the backs of males in spring. Found throughout the White Peak and in some parts of the Dark and South-West Peak, they utilise both terrestrial and aquatic habitats during their lifecycle. Ponds are a key habitat feature needed for breeding. The UK may hold up to 50% of the global population, so healthy populations in White Peak dewponds could be of high importance.

How vulnerable are great crested newts?

Great crested newts in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a poor current condition, and a moderate adaptive capacity.

The PDNP great crested newt population appears to be stable, having recovered from heavy historical declines. Terrestrial and aquatic habitats are both essential for the survival of this species, with ponds being most at risk in the face of climate change. Their longevity and the existence of metapopulations give this species some adaptability. However much depends on land management decisions and ongoing maintenance of ponds.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The PDNP great crested newt population suffered a severe decline between the 1960s and 1990s. Loss of breeding ponds and intensification of agricultural practices are reported as the main drivers. Some of this damage has since been reversed by a number of pond projects carried out by the PDNPA between 2004 and 2011. As great crested newt survival depends on metapopulations, these projects focussed on restoring key ponds in clusters and ponds that helped link neighbouring clusters together. Few individual ponds support large numbers of newts but each pond plays an important role in maintaining the overall population. The PNDP great crested newt population is now thought to be reasonably stable but may suffer further declines if pond restoration slows and ponds are lost.

Great crested newts are able to utilise ponds of varying condition but can be sensitive to water quality changes. They can tolerate poor water quality for short periods providing the pond has sufficient oxygen levels, and in the case of breeding ponds, contains enough plants suitable for egg laying. Particularly in areas of intensive management, ponds have been contaminated by fertiliser, slurry and herbicide application. Where this has occurred in large amounts, eutrophication has diminished the usability of this aquatic habitat. Silting up has also rendered some ponds unusable when water levels are reduced.

Land management and development continues to threaten great crested newts in the PDNP. Dewponds are susceptible to infilling as well as neglect which has led to pond loss as linings are damaged by drought or freezing. Clay or concrete linings may also be cracked by heavy livestock. Intensive farming practices have led to loss of terrestrial habitat used by newts. Where impacts on great crested newts are unavoidable, mitigation is usually carried out. They generally do well as a pioneer species in newly created habitat but long-term survival rates at receptor sites is largely unknown.

Other risk factors are predation and disease. In the aquatic habitat, they are often eaten at the egg-larvae stage by invertebrates, but introduction of fish, including stickleback, can result in loss of breeding success in ponds. In terrestrial habitat, they can be predated on by animals such as foxes, badgers, rats, and hedgehogs. Birds are known predators in both aquatic and terrestrial habitats. Diseases caused by pathogens such as ranavirus and chytrid fungi pose an unknown level of risk to great crested newts.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Pond habitat, essential for great crested newt breeding, is highly susceptible to changes in precipitation. Decreased rainfall and drought that is predicted to occur with hotter, drier summers is likely to affect the water levels in ponds and their suitability as habitat. Dewponds in the White Peak are particularly vulnerable, as these are shallow and depend on rainfall and run-off. Some ponds may become more seasonal, with drought periods increasing the chances of cracking the lining. Eutrophication could also increase. Loss of breeding ponds, particularly in summer when adult newts and larvae are using them, would lead to population decline. **[H]**

Extreme events including heavy rainfall and drought could affect great crested newts year-round in both their aquatic and terrestrial habitats. One study of great crested newts in south-east England found that heavy rainfall events in winter led to low annual survival rates. During drought periods, great crested newts are at risk of desiccation if water or shelter are unavailable. Loss of individuals throughout the year is likely to result in population decline, especially in areas with smaller metapopulations. **[M]**

Timing of migration from terrestrial habitat to breeding ponds has been linked to temperature. Great crested newts need night temperatures to be regularly above 4°C or 5°C and it appears that maximum temperature throughout winter also plays in role in determining pond arrival times. Later arrival at breeding sites has been recorded in Kent associated with increasing temperatures over several years. This later migration means that juvenile feeding times may be shortened, and ponds are at an increased risk of drying up before the juveniles are ready to leave the pond, causing accelerated development or fatality. Hotter summers and warmer winters with increased temperatures are likely to affect migration and could severely affect their ability of great crested newts to complete their life cycle. **[M]**

Increased carbon dioxide levels and annual average temperatures may lead to increased plant growth rate, both on land and in ponds. Vegetation growth on land could provide additional shelter to help offset hotter summer temperatures and reduce desiccation risk. In ponds, vegetation growth may also provide additional cover and material for egg-laying. In some ponds this may lead to increased breeding success, however in other ponds, excessive plant growth may reduce space for courtship displays or be unsuitable for egg laying. **[L]**

One climate change model found that in a low emissions scenario, great crested newt populations would remain relatively stable. However, a high emissions scenario could cause widespread population losses with only limited sites of suitable climate space remaining. **[M]**

Nutrient changes or environmental contamination

Great crested newts are sensitive to water quality changes. Extreme weather events, such as heavy rainfall, are likely to impact the nutrient loading of this habitat as increased run-off enters the pond. Eutrophication of some ponds is likely to occur causing a decline in the number of plants and animals that can survive there. Contaminated breeding ponds could cause severe population decline. **[H]**

Decreased rainfall in summer could also cause problems. Lower water levels will change the dilution of nitrates and other nutrients, which can affect great crested newt breeding success. Lower nitrate level ponds are essential for breeding. Ponds with a high abundance of aquatic plants that are surrounded by low intensity farming will be less vulnerable to eutrophication than ponds with few plants and high levels of nutrient input. Areas with fewer low nutrient ponds may see breeding success decrease. **[M]**

Increased levels of carbon dioxide could cause the acidification of some ponds. Changes to water chemistry are most likely to happen to smaller or shallower ponds, with eutrophication being a major threat. Some pond habitat may be affecting localised populations. **[L]**

Invasive or other species interactions

Aquatic habitats are particularly vulnerable to non-native invasive plants such as New Zealand pigmyweed and Canadian pondweed. With warmer temperatures predicted year-round, these plants are likely to have a longer growing season and may spread more easily as people transport them between water bodies. Although invasive plants are known to displace key plant species that are important for great crested newt egg-laying, one study found that great crested newts were unaffected by New Zealand pigmyweed. However, changes to water oxygen levels and loss of open spaces for courtship displays may still affect great crested newts at some sites. **[H]**

Increased annual average temperatures may cause diseases such as the fatal ranavirus to become more prevalent in PDNP great crested newt populations. Research has shown that ranavirus incidence dramatically increases when temperatures rise above 16° Celsius. As these temperatures become more common, outbreaks of ranavirus will be likely to increase in frequency. **[H]**

Human behaviour change

Great crested newts are sensitive to disturbance in both terrestrial and aquatic habitats. Increased visitor numbers are expected during hotter, drier summers and great crested newt habitat may be more frequently disturbed. Human activity around ponds is likely to damage terrestrial habitat and disturb great crested newts while they are resting. Disturbance by dogs and livestock may occur on land or in ponds themselves. **[M]**

Land use changes and management decisions associated with climate change will continue to impact great crested newts and their habitats. Intensive farming with higher stock numbers could disturb great crested newts and damage both ponds and terrestrial habitat. Conversion to arable could cause fertilisers to enter the water course and cause eutrophication. Where areas of land are abandoned, great crested newts will probably do well as they are good pioneers. Most ponds on the other hand, require active management to remain suitable habitat for great crested newts. **[M]**

Sedimentation or erosion

Wetter winters, drier summers and extreme events are expected to increase transport of sediment into ponds. Water quality may decrease, and ponds are likely to get shallower as they silt up. As a result, great crested newt pond habitat may be reduced in some areas. **[L]**

Other indirect climate change impacts

Warmer winters may increase foraging opportunities. Due to the cold, newts normally enter a period of low activity during winter. However, they can emerge and forage on warmer days. This may become more frequent, and it is possible that some positive effects will occur across some populations. However, warmer winter temperatures may cause higher metabolic rates in hibernating newts, resulting in lower body mass in the spring which can cause fewer eggs to be laid. **[L]**

What is the adaptive capacity of great crested newts? ***[Overall adaptive capacity rating: MODERATE]***

Great crested newts depend on both terrestrial and aquatic habitats. A network of ponds with good connectivity and suitable terrestrial cover in between is important for the whole metapopulation. The water quality of breeding ponds is vital for maintaining populations, however great crested newts seem to be able to cope with a wide variation of water quality across their wider habitat. Great crested newts usually only migrate between 250 to 500 m but can disperse as colonisers up to a kilometre away. If other suitable habitat is identified beyond this range, then translocation is an option. **[H]**

A relatively long-lived species, reaching up to 14 years in the wild, great crested newt populations can overcome poor breeding years. They can be resilient to the loss or damage of a few ponds as they move to other sites within their network. Adult diet is varied, and this increases their adaptive capacity. However, juveniles are limited to the food available in their natal pond. **[M]**

Environmental land management schemes and pond-oriented projects provide some funding for maintaining, restoring or creating great crested newt habitat. In the White Peak, the 'Proliferating Ponds in the Peak' project has helped to enhance a number of dewponds for great crested newts. There is potential for additional habitat to be created under the Department for Environment, Food and Rural Affairs (DEFRA's) Farming and Forestry Improvement scheme that helps with on-farm reservoirs. Funding is limited however, and it is likely that some ponds will be lost if pond restoration comes to a standstill. Pond availability and quality is a limiting factor for great crested newt populations and continual enhancement of this habitat is necessary to maintain and improve newt numbers. Loss of ponds could lead to the loss of a large number of great crested newts and population decline. **[M]**

Great crested newts are protected under the Natural Environment and Rural Communities Act 2006 and a European Protected Species, which gives full protection under The Conservation of Habitats and Species Regulations 2017. **[H]** A range of habitat management and restoration techniques, along with translocation guidelines are available from Froglife and other organisations. More research may be needed into techniques that offset climate change stressors. **[M]**

Key adaptation recommendations for great crested newts:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Minimise agricultural inputs to ponds, especially slurry, fertilisers and pesticides. Give consideration to good management of waste to improve catchment quality, including effective slurry store management.
- Systematically monitor invasive species in ponds, and control them where needed.
- Increase the use of sustainable drainage schemes for new developments.
- Translocate to new sites if needed. Undertake further research into translocation feasibility and sustainability.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

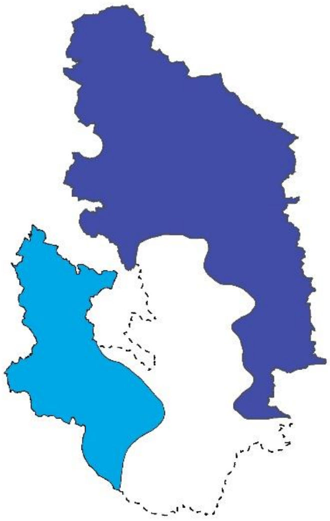
- Continue restoring and creating ponds across the PDNP: make it a priority especially near existing populations such as in the White Peak.
- Improve habitat between ponds to help connect them. Focus on terrestrial habitat vegetation and inter-pond distances.
- Monitor existing populations. Records of population size and habitat quality will be important to inform adaptation planning.
- Protect potential new habitat as well as existing habitat that is impacted through development proposals, particularly where it is near existing populations.

Lapwing

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Lapwing (*Vanellus vanellus*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Lapwing are a medium sized wader found in the PDNP year round, with a resident population as well as some departing for the coast in winter and some arriving from northern Europe.

They are easily recognisable by their looping, flapping flight, their distinctive 'peewit' call, and their black, white, and green plumage. They are most visible during their spring display flights, which are used to establish territory. They nest in scrapes, usually on farmland. Lapwing prefer varied habitat, with a short grass sward punctuated by taller grass stands, and wetter areas for feeding on soil invertebrates. Once widespread, lapwing are now a UK wide conservation concern.

How vulnerable are lapwing?

Lapwing in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, a potentially improving current condition but an only moderate adaptive capacity.

Lapwing in the PDNP have suffered historical decline, and their recovery has been variable despite targeted management. Some of the greatest impacts on lapwing populations will be in effects on their invertebrate prey. Drier conditions and increased flooding are likely to decrease the abundance of soil invertebrates, reducing lapwing breeding success. As a bird mostly associated with farmland, human behaviour changes will be very important for future lapwing populations – but these are difficult to predict. Lapwing have some capacity to adapt to a climate change, and this would be helped by conservation initiatives on in-bye land.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Lapwing in the UK have generally shown a slight decline over the past 20 years, but in the PDNP their numbers may be increasing. The 2004 Moorland Breeding Bird Survey found an increase in breeding lapwing numbers across the PDNP. However, recent work in the South West Peak has shown declines in many areas of farmland despite targeted management. Lapwing can utilise a variety of habitats including heather moorland, but prefer in-bye land and rush pasture. It is thought the increase seen may be due to lapwing adapting to nest in heather moorland where the sward is kept short. However, this suggests that numbers could in fact be much higher if more preferred habitat in better condition were available.

Lapwing and other waders have historically been displaced by commercial afforestation in the uplands, although woodland establishment is now largely on gully sides, which are generally poor lapwing habitat. Generalist predators such as carrion crows and foxes are a significant problem for lapwing in the PDNP, especially during the nesting season. Very high predator densities are present in some areas, causing predator control measures to be instigated to protect lapwing and other ground nesting birds.

Pasture in the PDNP is often 'improved' for livestock, reducing its suitability as lapwing habitat. Drainage has removed many of the wet flushes vital to lapwing feeding, while pesticide input has reduced the abundance of their invertebrate prey. High fertiliser and slurry input and silage production has resulted in unsuitable homogenous swards for lapwing. Changes in the soil fauna including reductions in worms in fields regularly treated with slurry, and high stocking densities can cause severe disturbance, soil compaction and nest trampling. These factors all correlate negatively lapwing populations, meaning that much of in-bye land in the PDNP is less preferred lapwing habitat. Sheep stocking - dominant in many parts of the PDNP - is generally seen as suboptimal for lapwing populations due to their grazing behaviour.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Wetter winters may drive phenological mismatches in lapwing. Lapwing have been found to lay earlier after wet winters, meaning that lapwing laying dates may advance. This could uncouple hatching dates from important annual cycles of invertebrate prey and agricultural practices. This could result in fewer available food resources during nesting, leading to reduced breeding success.

However, research in the Netherlands suggests that surface worms are a frequent prey item, and although these could be affected by drier conditions, they are still likely to be available even if lapwing laying advances.

If lapwing breeding time shifts sufficiently, it may fall outside of Natural England's current 'bird-breeding season' dates, potentially increasing disturbance from management. Higher temperatures in spring can also advance nesting and cause earlier grass growth and therefore earlier mowing. However, advanced nesting dates may be sufficient to counteract this. **[M]**

Greater frequency and severity of extreme events such as floods and storms may increase chick mortality. These extreme events put stress on adult lapwing and reduce their condition, but can be deadly for the smaller chicks. It is thought that chick mortality is the most important factor in lapwing population change. An increase in chick mortality could therefore drive a population decline in PDNP lapwings. **[M]**

Warmer winters could benefit lapwing by increasing winter survival rates. Survival is positively correlated with higher winter temperatures, meaning that fewer would be lost each year leaving more available to breed. Increased annual average temperatures also appear to be driving an eastward shift in lapwing. It is unclear what consequence this will have for PDNP lapwing, but it is unlikely that lapwing will be lost as a result. **[M]**

Other indirect climate change impacts

Drier conditions during spring and summer would affect the invertebrate prey of lapwing. Drier ground causes a reduction in soil invertebrates and causes them to move deeper into the soil. This causes foraging to become more difficult, as ground penetration resistance is increased and invertebrates are less accessible. Although lapwing also feed on surface invertebrates, soil invertebrates are the major food resource, especially for chicks. Wet ground during the early breeding season is vital for chick survival, with the condition of lapwing chicks positively correlated with earthworm consumption. Larger chicks are not thought to be capable of survival on insects alone, needing earthworms and other prey to grow and survive. Chick survival will therefore likely be reduced to some extent, lowering lapwing numbers in the PDNP. **[VH]**

Increased winter flooding may also affect soil invertebrate populations. In previously unflooded grassland, it is known to reduce soil macroinvertebrate biomass. Soil invertebrates are slow to recolonise areas they have been lost from, making it unlikely that populations can recover before spring breeding. Reduced invertebrate prey availability reduces chick survival, meaning lapwing returning to these fields will have reduced breeding success. However, winter flood areas remaining during the breeding season can provide a source of aquatic invertebrate prey. Lapwing habitat may therefore be enriched by a mosaic of flooded and unflooded fields, but this is hard to predict. **[H]**

Hotter, drier summers are likely to cause an increase in the frequency and severity of wildfires in the PDNP. This could affect lawing populations by removing nesting habitat and destroying nests. This would represent a full clutch loss for those birds affected, and reduce opportunities to re-nest, as previous nesting sites will no longer be suitable. **[L]**

Human behaviour change

Increased extent and creation of sea defences due to sea level rise is likely to affect lapwing at the coast. Managed realignment of the sea, as well as construction of hard barriers will remove some coastal habitat and cause remaining habitat to be squeezed, except where realignment involves creating new habitats suitable for lapwing. This will not affect the resident PDNP population, but for those birds that overwinter on the coast this could result in lowered winter survival rates and reduced breeding success upon their return to the PDNP. **[M]**

Future changes in land use will be significant in determining lapwing populations. As changing ground conditions and extreme weather events alter stocking levels, the suitability of pastureland for lapwing will change. Lapwing require a short sward, so abandonment of land is likely to be detrimental. As some land becomes unsuitable for grazing, stock numbers may increase on other land. This could increase nest trampling and soil compaction, reducing access to soil invertebrates. Soil compaction is a particular issue during flooding and waterlogging events, so increased surface water in some fields may further reduce their suitability as habitat. **[H]**

As climate change progresses, mitigation methods will become more common, potentially damaging national lapwing populations. Afforestation for carbon storage or natural flood management can remove lapwing habitat and replace it with unsuitable woodland or scrub. Wind farms can also displace lapwing and remove suitable habitat. Within the PDNP, planning may protect lapwing from upland developments, but the coastal wintering population may be at risk from both wind farms and tidal barrages. **[L]**

Hotter drier summers are likely to increase visitor numbers to the PDNP. This may increase disturbance and nest trampling of lapwing - not only by human footfall, but also by dogs off leads and occasionally vehicle traffic. Areas near to main paths and roads into and across the PDNP may have reductions or loss in populations of lapwing. **[L]**

Invasive or other species interactions

Increased average annual temperatures may increase populations of generalist predators by increasing their winter survival. High predator densities could be exacerbated, reaching critical densities in some areas. This would disadvantage lapwing and other ground nesting birds by increasing losses of both adults and chicks during the breeding season. **[H]**

Increased atmospheric carbon dioxide and other greenhouse gases, along with raised annual average temperatures may cause an increase in vegetative growth rate. This may decrease suitability of some habitat for lapwing, as visibility is important in nesting location. A taller grass sward reduces visibility and could cause loss of lapwing from some areas or increase the risk of predation. **[M]**

Winter flooding may however have a beneficial effect. Flooding can act similarly to grazing, keeping sward height short and thereby increasing habitat suitability for lapwing, provided there is no negative affect on earthworm or other invertebrate populations. However, as this would mainly affect pastureland the human response to such change would be critical. **[M]**

Nutrient changes or environmental contamination

Changing conditions in the PDNP may lead to intensification of agriculture to adapt to climate change effects, such as increased applications of fertiliser or pesticides. Pesticides reduce invertebrate populations directly, but fertiliser has also been shown to decrease insect body mass. Combined with increases in drainage reducing earthworm populations, this could lead to reductions in food resources, reducing lapwing condition and breeding success. **[H]**

Sedimentation or erosion

Increased erosion on coastal habitats such as saltmarsh and mudflats may have negative effects on the coastal wintering lapwing population. Removal of material or excess deposition has the potential to damage soil invertebrate populations, reducing their availability. This may lead to reductions in wintering survival rates, as well as poorer condition of returning lapwing. Overall, breeding success of coastal wintering lapwing could be reduced. **[M]**

Increased winter rainfall and severity of summer storm events will likely lead to increased runoff in the PDNP. This is unlikely to be an issue for those lapwings nesting on well-vegetated pastureland, but heathland nesting birds may be more at risk. Upland soils are already relatively thin, allowing soil erosion to expose heather roots easily, causing root damage. This damage can change the vegetation mosaic, potentially reducing the suitability of heather moorland for lapwing nesting and foraging. **[H]**

What is the adaptive capacity of lapwing? ***[Overall adaptive capacity rating: MODERATE]***

As a single-brooded ground nesting bird with specific nesting site requirements, it appears there are some barriers to adaptation in lapwing. However, lapwing have shown an ability to use a variety of habitats with suitable ground and sward conditions, and large variation in migration strategy affords populations some resilience to changing conditions. Lapwing have already shown some adaptation to climate change by advancing laying dates and shortening migration routes due to earlier warmer conditions. **[M]**

Lapwing habitat in the PDNP is generally quite fragmented. Although there are large areas of well-connected in-bye land, the specific requirements of lapwing and their general aversion to grassland 'improvement' means that much of this is not fully utilised. Lapwing dispersal is relatively low, with most nestlings returning to breed less than 10 km from their natal site. Their capacity to adapt is lessened by this site faithfulness. Some models predict lapwing climate space moving, leading populations to move north and west out of the PDNP by the late 21st century. However, other modelling shows the PDNP still within lapwing climatic range, leaving low confidence in this prediction. **[L]**

Some economic resource is available for adaptation in the PDNP. Many environmental land management schemes focus on farmland waders including lapwing. These schemes have been shown to be effective for farmland birds across Europe, or at worst not harmful. However, it is questionable whether these schemes will be effectively implemented. There are good opportunities but much uncertainty surrounding the UK's exit from the Common Agricultural Policy. **[L]**

Some institutional support is available for lapwing in the PDNP. Projects such as the now defunct PDNPA Wader Recovery Project and the current South West Peak Partnership Working for Waders aim to protect farmland waders, but have had mixed success. The ability to instigate positive change on private land is wholly dependent on cooperation from landowners. Some lapwing habitat is within Site of Special Scientific Interest (SSSI) and Special Area of Conservation (SAC) designation, which has been shown to be beneficial. Lapwing are a red listed bird species in the UK. **[L]**

Management interventions to improve habitat suitability for lapwing and other farmland waders are reasonably well known. Rewetting, lowering stock densities, and reducing agrochemical inputs can all help lapwing populations recover. The issues arise in putting this knowledge into practice, and current agriculture subsidy systems can make this difficult. **[L]**

Key adaptation recommendations for lapwing:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Reduce chemical inputs to fields to allow soil invertebrate populations to recover.
- Stronger grazing pressure in autumn and delayed lower pressure grazing in spring can generate the correct sward conditions, while minimising trampling and disturbance.
- Rush management should be planned with the needs of different species in mind, some suitable areas of long rushes should be left intact.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Future increases in PDNP arable land use may become a resource for PDNP lapwing populations. In this scenario, management of this land should be sensitive to this species
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Wetland restoration should be a priority; both upland rewetting and lowland drain blocking will help.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Heterogeneity in surface water conditions is beneficial for lapwing chick survival. Some shallow wet features should be maintained throughout the breeding season. Generally wetter conditions are also beneficial.

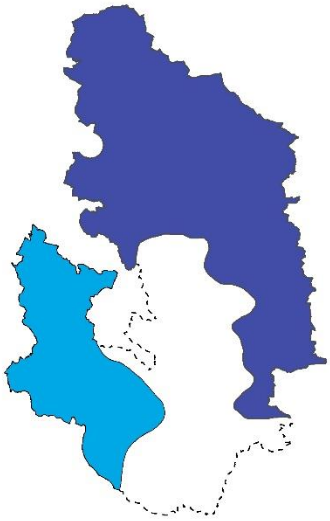
Merlin

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Merlin (*Falco columbarius*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The merlin is the UK's smallest bird of prey, not much bigger than a blackbird. Merlin mainly feed on small birds such as meadow pipit, and usually take their prey on the wing. Similar in appearance to the kestrel, they are distinguishable by their smaller size and stockier build, as well as their darker back and white stripe above the eye. Merlin are a sparsely distributed breeder across PDNP moorland, often migrating to coastal areas in the winter. A true moorland specialist, they have not recovered well from historical population crashes. The PDNP represents the most southerly edge of the Pennine breeding population, and the most southerly English breeding population.

How vulnerable are merlin?

Merlin in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor current condition, and a low adaptive capacity score.

Merlin are a scarce species in the PDNP, with a small population that has not rebounded as well as some other raptors in recent years. Climate change poses a significant threat to merlin, as the PDNP and much of the UK will become unsuitable as temperatures rise. Merlin are very likely to be extinct from the PDNP by the end of the 21st century. Changes to merlin nesting habitat, especially mature heather stands may also put pressure on populations. Despite being a mobile species and able to change nesting habits, merlin are unlikely to be able to adapt enough to offset climate effects. This is due in part to insufficient support and management, but is largely due to the extent of climate impact.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

Merlin have a small population in the PDNP, being sparsely distributed across moorland in the Dark and South West Peak areas. Populations do not seem to be recovering as well from historical persecution and pesticide use compared to some other raptor species, possibly because of their more specialised lifestyle. The 2004 Moorland Breeding Bird Survey found merlin numbers to be increasing, though they are still a rare sight in the PDNP. 24 pairs were estimated to have nested in the PDNP in 2018. It is unclear whether merlin were ever very populous in the PDNP, with some historical sources describing their rarity.

Human behavioural and land use changes were probably the main causes of historical merlin decline, and still affect merlin populations today. High levels of organochlorines and other pesticides contributed to large-scale decline of invertebrates, depleting food resources for prey birds. Bioaccumulation of pesticides through the food chain also directly caused some merlin fatality. The most damaging pesticides are now banned, and bird of prey numbers have increased, but pesticide effects will still be present.

Illegal persecution is also a major threat to merlin, which are too small and quick to be shot easily but can still be affected by poisoned bait and other traps. Legal predator control may also affect merlin by decreasing crow numbers. As well as nesting on the ground, merlin can use abandoned crow nests in trees where they often nest in association with crows as an early warning against larger raptors. As much of PDNP land is open access, ground-nesting merlin can easily be disturbed and nests trampled. However, there is weak evidence for this being a significant effect.

Merlin are unlikely to be significantly impacted by predation, despite the high predator densities in parts of the PDNP. Studies in the Shetland Isles have shown no significant effect of nest predation on population decline.

Wildfire in the PDNP has probably had an impact on merlin numbers, destroying potential nesting and feeding habitat such as heathland and grassland. 552 wildfires occurred within the PDNP boundary between 1976 and 2018.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

As average annual temperatures increase, the merlin climatic envelope is very likely to contract northwards. UK merlin are at the southernmost edge of their European breeding range, so northward range contraction would result in the loss of breeding populations in the PDNP. Multiple models show climate suitability for merlin being lost from much of the UK over the 21st century, with only the Scottish Highlands remaining a refuge. The PDNP will be one of the first places to experience this loss. European winter migrants may still visit the PDNP after this loss, but the breeding population is unlikely to remain. **[VH]**

Wetter winters and a greater frequency of summer storms may lead to higher episodic nitrogen deposition, especially in the uplands. Excess nitrogen availability causes increased sensitivity of heather to drought and frost, meaning some mature stands may be lost. This would represent a loss of nesting habitat for merlin, decreasing their breeding opportunities. **[M]**

Drier summers may result in increased productivity for merlin. Wet summers decrease breeding success in aerial predators, as the activity and visibility of their avian prey is reduced. Less summer precipitation may therefore increase food availability and breeding success in merlin. However, due to density dependent effects in population change, it is unclear whether this will lead to an increase in population size. **[M]** An increase in the frequency and intensity of spring and summer storms may counter this effect, as heavy rain events are particularly detrimental to foraging success. **[M]**

Human behaviour change

An increase in visitor numbers due to hotter drier summers may cause greater disturbance of nesting merlin. It is unclear at what distance disturbance is significant, with estimates ranging from less than ten to 500 metres. This variation may be due to differences in ground and tree nesting merlin, or nesting stage, with merlin at a later incubation stage being less willing to abandon eggs. If the disturbance distance is at the higher end of this range, visitors may disturb merlin without even realising they are present. Decreased nesting success would result from this.

Climate change may cause declines in red grouse numbers, and this could result in an increase in illegal raptor persecution. Despite not being a main target for persecution, merlin will still be affected by poisoned bait and other traps. Merlin fatalities due to persecution could have a significant effect on the already small population. Other agricultural landowners may also react to changing conditions by intensifying management. This may decrease farmland bird populations both in the PDNP and at coastal wintering grounds. A reduction in food resource would decrease merlin fitness and reduce overwintering survival. **[M]**

As sea levels rise, mitigation efforts may prove detrimental. Hard flood defences and squeezing of the remaining wintering habitat would increase competition for resources and could reduce abundance of small avian prey such as meadow pipit and dunlin, resulting in reduced wintering survival for merlin. **[L]**

An increase in upland afforestation as a carbon capture method may have mixed effects on merlin populations. Birds of open moorland merlin are usually negatively associated with woodland, as they are replaced by generalists and woodland species. Conversion of heathland and grassland to woodland would therefore decrease habitat suitability for merlin and their avian prey. However, trees on moorland edges can provide nesting opportunities for merlin. European merlin populations are generally tree nesting and UK merlin are increasingly using trees as nesting habitat, particularly on woodland edges where they provide a good vantage point, so newly created forests may represent increased nesting resource for merlin. **[M]**

An increase in the frequency and severity of flooding events may lead to increased natural flood management efforts. In the PDNP, this is likely to be through moorland rewetting and restoration of natural hydrological processes. Increased heterogeneity of habitat may benefit merlin by increasing nesting and feeding opportunities, with the habitat mosaic meaning nesting and feeding areas are less separated. Clough woodland establishment may also increase nesting habitat on moorland edges. **[L]**

Invasive or other species interactions

Warmer wetter winter conditions may increase heather beetle numbers, meaning that outbreaks would be more likely. Mature stands of heather may be lost, removing some merlin nesting habitat. Heather may be replaced by fast growing colonisers like bracken, which could take advantage of the warmer climate to spread. It is unknown whether merlin will take advantage of bracken stands or move elsewhere. Heather moorland may also be lost to grassland, increasing available feeding habitat but removing breeding habitat. **[H]**

Increased annual average temperatures may lead to an increase in generalist predators due to higher winter survival rates. Nest predation does not appear to have a significant impact on merlin, but at very high predator densities, animals such as foxes could conceivably take merlin young. Higher temperatures may also increase disease and parasite prevalence. It is unclear how this would affect merlin, but the greatest effect may be on their avian prey. Fewer and poorer condition prey would lead to poorer condition of merlin, lowering fitness and decreasing breeding success. Merlin wintering grounds may also be affected by high temperatures, with high spring temperatures being correlated with algal blooms in estuaries. These blooms could decrease food resources for the merlin's avian prey, leading to reduced fitness before migration. Increased migration fatalities and decreased breeding success upon their return may follow. **[L]**

Sedimentation or erosion

Increased erosion due to sea level rise will cause changes at coastal wintering grounds. Erosion may remove some estuarine habitat and change the sediment composition in other areas, reducing invertebrate abundance in the substrate and removing feeding habitat for avian prey. A reduction in small wintering birds would cause reduced wintering survival in merlin, resulting in fewer and poorer condition, birds returning to the PDNP. **[H]**

An increase in winter rainfall and summer storm events may lead to increased erosion, damaging merlin nesting habitat. Heather moorland in the PDNP is often on thin peat soils, making it highly susceptible to erosion. Erosion exposes heather roots, making the plants more susceptible to drought and winter desiccation. As a result mature stands of heather may be lost. As these stands are essential for ground nesting merlin, this would cause displacement of some birds and potentially drive a move towards tree nesting habits. **[H]**

Other indirect climate change impacts

Greater occurrence of winter flood and waterlogged conditions are likely to reduce below ground biomass allocation in heather and other plants in affected areas, causing root dieback. Heather with lower underground biomass allocation is more susceptible to stressors such as drought and frost. As a result, some heather may be lost and community composition altered, resulting in less suitable nesting habitat. **[H]**

Hotter, drier conditions in spring and summer may lead to an increase in wildfire in the PDNP. This would be especially damaging during the nesting season, as nests could be destroyed. Burns covering large areas could also prevent re-nesting opportunities, as merlin tend to be faithful to an area. **[L]**

Higher summer temperatures and an increase in drought may cause excess stress on heather. Heather stands, particularly those on south facing slopes, may die off due to heat stress. Older heather stands suitable for nesting may be more vulnerable to this. Heather that remains may no longer grow tall enough for merlin nesting. As a result, nesting opportunities may be reduced. **[L]**

Nutrient changes or environmental contamination

Increased atmospheric carbon dioxide and nutrient availability may cause an increased plant growth rate, affecting merlin feeding grounds. An increased growth rate, coupled with a longer growing season due to increased temperature, may cause grass growth and dominance to increase, as faster growing grasses will be better able to make use of available resources. This may encourage higher livestock levels on acid grasslands, leading to reduced populations of merlin prey. However, stress tolerant grasses on moorland are likely to be limited by other factors such as nutrient availability, so this effect may be small. **[L]**

What is the adaptive capacity of merlin? ***[Overall adaptive capacity rating: LOW]***

As migratory birds, merlin have few barriers to movement and may be able to move with changing conditions. However, the lack of habitat further north in the PDNP is expected to cause their loss from the area. Merlin in the South West Peak may be able to move to Dark Peak nesting sites, but as their climate envelope continues to move they too will likely move northwards out of the PDNP boundary. **[H]**

Merlin have shown some evidence of adaptability in the face of change. Site faithfulness due to territory holding is a significant barrier to adaptation in individual birds, but would not prevent the population shifting, albeit slowly. Despite their current inability to adapt to urban spaces in the UK, this does occur in North America. This may be related to the ground nesting habits of most UK merlin. However, they have shown some movement towards tree nesting habits, although this has been in conifer plantations. **[M]**

Some economic support for adaptation is available in the form of environmental land management schemes. These may be effective in preserving some merlin feeding habitat, as acid grassland on moorland edges is at risk of conversion to more productive 'improved' grassland. However, in many cases such schemes are unlikely to be effectively implemented, and their future is very much uncertain. **[L]**

Several institutions that could make adaptations exist within the PDNP, and in the case of the National Trust own much of merlin nesting habitat. Merlin are also specially protected by Schedule 1 of the Wildlife and Countryside Act 1981, are listed in annex 1 of the European Commission Directive on the Conservation of Wild Birds. They are a red listed bird species in the UK. The South Pennines Special Protection Area (SPA) is also designated for birds and specifically mentions merlin in its citation. However, current SPA provisions are not thought to be adequate for merlin conservation, and additional provisions may be required. **[H]**

Compared to other raptor species, there is a lack of information on merlin. This means that management interventions are unlikely to be as effective, as specific knowledge of species ecology is needed to inform decisions. Even if effective, management is unlikely to be able to offset climate change effects on merlin. **[L]**

Key adaptation recommendations for merlin:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Greater focus on preventing bird of prey persecution in the PDNP is needed, as well as prosecution of offenders.
- Lower grazing intensity is beneficial to both merlin and their avian prey.
- Further research is required to understand drivers of population changes. Breeding success has been relatively good so it is important to uncover the reasons why Merlin are not doing well in the PDNP.
- Undertake research or collaboration with organisations linked to wintering grounds.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

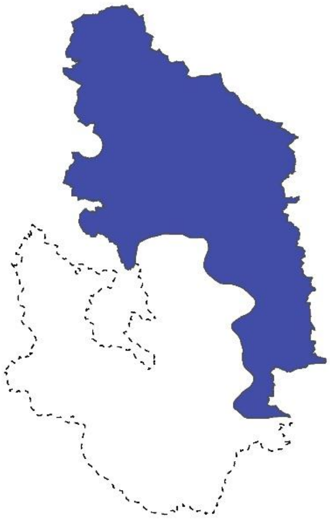
- Increasing the heterogeneity of moorland vegetation has been suggested to be beneficial to merlin.
- Woodland creation on moorland edges may provide nesting habitat and allow merlin to be more adaptable.

Mountain hare

Overall vulnerability rating:

Very low	Low	Moderate	**High**	Very High

Feature(s) assessed:



- Mountain hare (*Lepus timidus*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The mountain hare is the UK's only native lagomorph. It is easily recognised by its small ears with black tips, white tail, grey-brown coat in summer and a white coat in winter. Found in upland habitats, particularly heather moorlands, it was reintroduced to the PDNP for hunting in the late 1800s. The current population is divided by roads and river valleys into three main subpopulations. The PDNP is an important stronghold for this species, containing the only surviving reintroduced mountain hares in England.

How vulnerable are mountain hares?

Mountain hares in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, coupled with a moderate current condition, and with a moderate adaptive capacity.

Currently with a declining population, mountain hares are particularly vulnerable in winter as energy demands are high. Healthy habitat for shelter and food are vital for the continued survival of this species. While this is an isolated population, the high population growth rate of mountain hares gives them a good chance at recovery from climate change events.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

The PDNP mountain hare population has increased significantly since re-introductions in the 1800s. However, recent surveys by Sorby Natural History Society and other organisations suggest there has been a decline over the last decade. This is possibly due to the culls that are sometimes carried out in an attempt to minimise louping ill virus transmission to red grouse. While mountain hares themselves are no longer hunted for sport, culling is still taking place in some areas under game management laws. Populations are known to be cyclic, with losses of up to 90% every 5-15 years, but experts suggest the current decline is beyond this normal cycle. Total population estimates are difficult as they are extrapolated from a limited number of sightings that are used to calculate habitat density estimates. A 2018 study estimates 1,500-5,000 individuals in the PDNP. Other studies indicate it is likely to be at the lower end of this.

Land management such as heather burning and grazing can affect mountain hare populations. Heath and cotton-grass habitats containing a range of food plants are favoured over grasslands. While mountain hares show a preference for young heather growth, they can also survive on old heather stands and birch or willow scrub. A mixture of heather growth created through controlled burning may enhance foraging habitat. On the other hand, eroded areas of bare peat lack vegetation for food and shelter. Wildfires continue to pose a threat to the upland habitat needed by this species.

Other risk factors for mountain hares are predation and disease. Foxes and stoats are the main known predators, while birds of prey may take some young. Diseases such as louping ill virus and intestinal parasites may cause body condition to deteriorate and lead to the loss of some individuals and poor fecundity in others. Some individuals are also lost as road casualties.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Wetter winters with cold snaps and persistent heavy rain pose a threat to mountain hares. While they do well in the current climate in England and Scotland, their fur is poorly adapted to being wet making them prone to increased heat loss when they are exposed for long periods. Mountain hares have limited cover to shelter in on cold wet days, which further increases their mortality risk. Extremely wet winters could lead to the loss of some mountain hares. **[M]**

Hotter, drier summers on the other hand are likely to benefit mountain hares. Increased temperatures have been associated with higher breeding success. Coupled with the possibility of an extended breeding season, it seems probable that mountain hare populations will increase in the PDNP during the warmer months. **[M]**

The predicted rise in carbon dioxide in the atmosphere and longer, warmer growing season may lead to increased plant growth rate in some areas. Increased vegetation that provides additional shelter and foraging is likely to benefit mountain hares right across their range. Shelter that protects them from extreme weather and predators along with the increased food availability could lead to a population increase. **[L]**

Human behaviour change

Land use changes and management decisions would affect mountain hare habitat and local populations. Dependent on certain food plants such as heather, changes to this vegetation mosaic could have both positive and negative impacts on mountain hares. Where there is increased grazing and loss of vegetation cover, population decline is likely. However, where there is favourable land management that optimises shelter and food options, populations are likely to remain stable or increase. **[M]**

Mountain hares are sensitive to disturbance, particularly during the winter months. With increased tourist numbers anticipated year-round in the PDNP, mountain hares are more likely to be disturbed by people out on the moors. One European study has shown that increased disturbance causes increased stress and creates higher energy demands as mountain hares are flushed out of their resting spots interrupting key activities such as grooming and the re-ingesting of faecal pellets.

Higher energy demands in winter when food is already limited may be detrimental to the survival of frequently disturbed individuals. **[L]**

Other indirect climate change impacts

Warmer winters with reduced snow cover may increase the predation risk for mountain hares. The white winter coat is the perfect camouflage in a snowy landscape, but it stands out against exposed vegetation leaving them more vulnerable to predation. Temperature regulation in warmer winters may also be a challenge with their winter coat. Population decline in areas with little or no snowfall is probable. **[M]**

Mountain hares and their habitat are sensitive to wildfire. Hotter summers with increased drought events create a higher risk of wildfire in the uplands, especially in areas dominated by heather. Large areas of mountain hare habitat are at risk and mountain hares may be lost in fires. **[L]**

Invasive or other species interactions

Disease outbreaks and predation levels may increase with year-round warmer temperatures. Lagoviruses that affect rabbits and hares have the potential to spread quickly as populations overlap in some areas. Pockets where both rabbits and mountain hares are present have a higher infection risk that could negatively affect local populations. Survival rates of ticks, pathogens, and predators may all be increased by the warmer temperatures. An increase in disease outbreaks and predation is likely to lead to population decline in affected areas. **[M]**

Sedimentation or erosion

Vegetation cover is vital for mountain hares as shelter and as a food source. Erosion caused by heavy rain poses a threat to this habitat as areas of vegetation and peat may be washed away leaving only exposed ground. As mountain hares are less comfortable using areas of bare peat, their habitat size may be reduced. In areas of extreme erosion populations may become more fragmented or even lost. Extreme events such as flooding and drought would worsen the situation, further altering the habitat extent and possibly causing the loss of some mountain hares. **[L]**

What is the adaptive capacity of mountain hares? ***[Overall adaptive capacity rating: MODERATE]***

The mountain hare is confined to three main subpopulations in the PDNP. Reintroduced to several places in England and Wales, the PDNP population is the only one that survived. The population is isolated in this upland environment and depends on specific habitat conditions in both summer and winter in order to survive. There is limited space to expand. However high population growth rates give them good resilience in recovering from population crashes. Disease and harsh weather events may be overcome if remaining individuals have a successful breeding season. Damage to or loss of habitat is likely to affect adversely their recovery and may even make it impossible in some areas. **[M]**

Mountain hares are protected under the Wildlife and Countryside Act (1981), where killing, injuring or taking in the closed season are an offence. They are listed in Annex five of the EC Habitats Directive as a ‘species of community interest whose taking in the wild and exploitation may be the subject of management measures’. They are also a priority UK Biodiversity Action Plan (UK BAP) species. This gives them additional protection and encourages conservation action by relevant local authorities. **[H]**

Land management and habitat availability play a significant role in determining mountain hare distributions and population survival rates. Various organisations such as the National Trust and PDNPA manage and restore moorlands with the aim of increasing vegetation cover and reducing erosion. While funds are not specifically designated for mountain hare conservation, habitat maintenance and improvements are likely to help mountain hares partially overcome climate change effects. Mountain hare sightings data may help with long-term population monitoring and management responses. **[H]**

Key adaptation recommendations for mountain hares:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Work with partners to reduce or end culling of hares in PDNP.
- Continue moorland restoration work to reduce bare peat and improve mountain hare habitat.
- Continue to gather mountain hare sightings data and encourage the public to report sightings. This will help inform future adaptation planning.
- Set up a mountain hare monitoring plan: to better understand local population dynamics and to identify risks, opportunities and key areas. Further research is required.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Limit disturbance at known sites: particularly in areas with high visitor numbers.
- Install wildlife corridors, such as underpasses, to increase connectivity between populations and decrease road casualties.

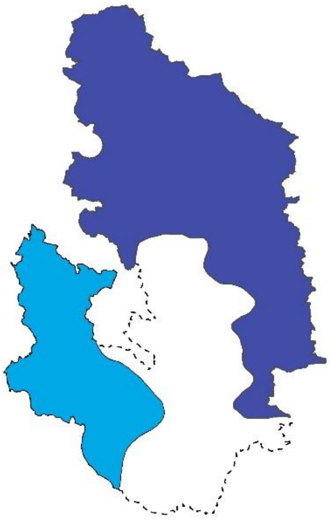
Pied flycatcher

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Pied flycatcher (*Ficedula hypoleuca*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

A small bird and a summer visitor to the PDNP, the pied flycatcher spends its winters in West Africa and returns to nest in the spring. It is easily recognisable by its distinctive black and white 'pied' plumage. It can be found in upland broadleaf woodland, where it nests in knotholes and nest boxes and performs its characteristic fly catching behaviour. Caterpillars, slugs, and other ground-based prey are also an important food source, especially during nesting season. The pied flycatcher is a red listed bird in the UK, and the PDNP population is important for its conservation.

How vulnerable are pied flycatchers?

Pied flycatchers in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but a moderate current condition, and a moderate adaptive capacity.

Pied flycatchers in the PDNP appear to be doing reasonably well, with known populations doing better than the national average. Trophic mismatches with their nesting food sources are likely to increase as climate change shifts the timing of annual events such as migration and leaf bud burst. Climate change effects in West African wintering grounds will also be important. The moderate adaptive capacity of PDNP populations mostly relies on good management of key sites.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Pied flycatchers are nationally declining, having decreased by 42% in the last 22 years and ceased breeding in many places. Known populations in the PDNP appear to be doing better than the national average. However, there has never been a full census so some 'unknown' populations may have already been lost. Nesting boxes are kept for pied flycatchers in Padley Gorge and Stanage woodlands, and other species are prevented from using them. Populations in such locations are currently stable. Climate change is already having an effect on pied flycatchers in the UK. This is mostly through trophic mismatch due to advanced leaf budding date. See section '*Other indirect climate change impacts'* below for more detail.

A study in Stirling found grey squirrels to affect 4-7% of nests, which if replicated in the PDNP would imply a large loss of young birds to nest predation. However, many of the PDNP population nest in boxes that are strengthened, so this may lessen predator impact.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Warmer conditions earlier in the year are likely to increase the phenological mismatch between pied flycatchers and their caterpillar prey. This has already occurred as warming has moved leaf budding dates earlier in the year, and only the more adaptable caterpillars have advanced their population boom to match. As caterpillars provide a large proportion of pied flycatcher food during nesting, this mismatch has left them with less food available during this crucial period. Some birds have moved their nesting dates forward to match, but pied flycatchers are less able to do so, possibly due to other factors influencing migration dates. **[VH]**

Summer storm events may reduce breeding success. Storms can put environmental stress on pied flycatchers and reduce the activity of their invertebrate prey, especially flying insects. Breeding success would be lowered as a result and adult condition reduced, causing increased fatalities on return migration later in the year. **[L]**

However, increased average annual temperatures may have a positive effect on pied flycatcher populations. Higher temperatures during nesting correlate with larger clutch sizes. This may be due to greater invertebrate activity and abundance, but the full causation is unclear. Both nestling and fledgling success are also increased by warmer conditions. Decreased precipitation during nesting is also correlated with increased nestling success. The causation is again unclear, but again may be related to increased invertebrate abundance and activity. The combined effect is that warmer drier springs are likely to lead to increased breeding success in pied flycatchers. **[H]** The relationship of these effects and phenological mismatch is unclear.

Other indirect climate change impacts

Delayed onset of the rainy season in West Africa may also increase phenological mismatch. If rains arrive later in the year, the start date for migration to the UK may also be delayed. This effect could increase as the gap widens between the advanced leaf bud burst in the UK and delayed arrival. This will limit the ability of pied flycatchers to adapt to earlier bud burst, while UK resident bird species may adapt and therefore have a competitive advantage. **[M]**

Changes to the wintering grounds may have a significant effect. Predicted rainfall change across West Africa is variable, so some wintering sites may become more desirable, but others less so. Droughts may play a role in this, becoming more prevalent and severely reducing the suitability of habitat. Desertification is likely to be significant, with some habitat lost as the Sahara expands. Sea level rise will also affect wintering grounds. Coastal sites may be lost as sea levels rise, and many more affected by saltification, reducing their suitability. This will increase competition for resources at the remaining suitable sites, reducing the condition of birds before their migration. Combined with the challenge of crossing a larger and drier Sahara, this may lead to fewer birds returning to the PDNP in the spring. **[M]**

Invasive or other species interactions

Increased average annual temperatures could increase the prevalence of pied flycatcher parasites. This would reduce bird condition overall, and certain blood parasites have been shown to cause shorter wing and tail length in males. This would be a particular problem during migration, where these effects can increase migration fatalities and delay arrival in the UK. The timing mismatch between pied flycatchers and their spring nesting food sources could therefore increase. **[M]**

Human behaviour change

Hotter drier summers may lead to increased visitor numbers in the PDNP. The effects of increased disturbance will be greatest at popular sites such as Padley Gorge - an important nesting location. However, this impact should be small compared to other factors acting on pied flycatcher populations. **[L]**

Climate change mitigation efforts may lead to an increase in habitat for pied flycatchers. Woodland establishment for carbon offsetting and natural flood management may increase available habitat for this and other woodland birds. However, as mature trees with knotholes are preferred this is unlikely to increase significantly habitat in the short term unless nest boxes are installed. **[L]**

What is the adaptive capacity of pied flycatchers? ***[Overall adaptive capacity rating: MODERATE]***

The PDNP populations of pied flycatchers are small and relatively isolated, and so are quite vulnerable to change. However, the pied flycatcher has a large summer range across Europe and Asia, and there is gene flow and migration between breeding sites - pied flycatchers hatched in the UK are known to have bred in the Netherlands. This means that birds from elsewhere could bolster the PDNP populations or in an extreme case recolonise the PDNP.

Climate change will affect European countries differentially, so climate change refugia may contain healthy pied flycatcher populations that can spread to the UK, for example montane populations in southern Europe are predicted to be better off than UK populations. **[M]**

Pied flycatchers are relatively resilient to habitat change. Although they require broadleaf woodland, they are known to inhabit a variety of tree assemblages, meaning that they may be able to cope with future woodland change. They also feed on a wide variety of invertebrate prey, so changes in the invertebrate community may be possible to overcome. **[M]**

Pied flycatchers are a favourite among birdwatchers, so organisations such as the RSPB, National Trust, and PDNPA are likely to continue working on their conservation. Unfortunately, there are few economic incentives for private landowners to work on their conservation, as even creation of woodland habitat is a less favoured environmental land management scheme option. Some areas of importance to pied flycatchers are covered by Site of Special Scientific Interest (SSSI) designation, including important sites such as Stanage woodlands and parts of Padley Gorge. However, UK based institutions, schemes, and designations will only be effective up to a point, as the West African breeding grounds are also vital to pied flycatcher populations. **[M]**

Management practices for pied flycatchers are relatively well known, having been a focus in some sites for a long time. Nest boxes are known to improve survival, being preferred by pied flycatchers to natural cavities. Studies at the Longshaw Estate have shown that new boxes are beneficial, with an increase in uptake after these were built. Nest boxes facing south-west are associated with reduced breeding success, so orienting boxes correctly is a common practice. ‘Corking’ of nest boxes is used to prevent native birds from moving in before pied flycatchers arrive, and so reduce nest competition. This could ameliorate some of the effects of trophic mismatch. Pied flycatchers are a very well-studied species both in the UK and Europe, and are relatively well understood, allowing management practices to be more effective. However, it is not fully understood the extent to which pied flycatcher populations are dependent on breeding success compared to wintering survival, but it is thought that wintering survival is a significant factor. Therefore, UK based management plans can only ever be partly effective. **[VH]**

Key adaptation recommendations for pied flycatchers:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Suitable broadleaf woodland and new broadleaf woodland in the Dark and South West Peak should be fitted with nest boxes as soon as possible, including increasing nest box numbers within existing sites. This is the best way to increase pied flycatcher habitat and would help to improve resilience.
- Implement known best management practices on nest boxes such as corking and orienting away from south-west. Ensure continuity of management. More sustainable long term strategies may need to be considered.
- Increased upland woodland establishment, especially oak woodland, will increase habitat for pied flycatchers.
- Manage for increased Lepidopteran (caterpillar) populations to increase nesting food supply for pied flycatchers.
- PDNP based management can only do so much for pied flycatchers and other migratory birds. Partnership with West African conservation groups and others along the migration route would be the best way to increase winter survival.
- Investigate natural dynamic land management for pied flycatcher and other species. Pilot a ‘rewilding’ or ‘wilding’ trial scheme with no fixed conservation aims and monitor the impact on this feature.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

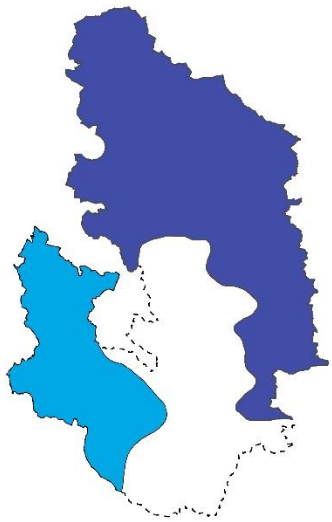
Ring ouzel

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Ring ouzel (*Turdus torquatus*)



Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The ring ouzel is a distinctive thrush species found in the PDNP uplands. Despite looking quite similar to the more common blackbird, it is easily distinguishable by its white bib. A summer migrant, ring ouzel spends winter in North Africa before returning to the PDNP to breed. Often nesting in the rocks and cracks of gritstone landforms, ring ouzel are found in the Dark and South West Peak and have a stronghold in the Eastern Moors area. Their diet is similar to that of other thrushes, consisting of earthworms, beetles, and other ground invertebrates as well as berries. As such, adjacent areas with feeding resource including unimproved grassland, scrub, and verges are essential to good ring ouzel habitat. The ring ouzel is a rare upland species in the UK, with the PDNP holding a significant proportion of the UK population.

How vulnerable are ring ouzel?

Ring ouzel in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a declining current condition, and a low adaptive capacity.

Ring ouzel population trends in the PDNP appear to be following the national trend, declining and retracting to upland locations. Changing conditions and mismatch in the timing of food availability may mean that in the future, suitable habitat can only be found north of the PDNP. Greater disturbance from increased visitor numbers may also have a significant effect. Despite their reasonable dispersal ability, ring ouzel are unlikely to adapt quickly enough to match changing conditions, and management interventions are not well known enough to counter this.

Overall potential impact rating: High

Overall adaptive capacity rating: Low

Current condition:

The ring ouzel has undergone significant historic decline across the UK, with numbers continuing to drop in recent years. This trend appears to be true for PDNP ring ouzels, with the 2004 Moorland Breeding Bird Survey showing a decline in abundance and territory. Ring ouzel distribution appears to have contracted to upland moorland sites with good heather cover, away from conifer plantations. There is much of this habitat type in the PDNP, which may imply the PDNP is more suitable than other areas, although there is no evidence to explain different rates of decline across the country. Conifer plantations are currently being reduced in area in the PDNP, giving possible opportunity for population expansion. Predation of nestlings and fledglings may be a limiting factor in ring ouzel populations, but it is unclear to what degree.

Ring ouzel are very sensitive to disturbance. This is a significant factor in the heavily visited PDNP. As many nest in gritstone crags, disturbance from climbers and scramblers is an ongoing issue. Ring ouzel are thought to have been lost from the Roaches due to disturbance from climbers. Recent efforts to limit access to crags during nesting season have been successful in reducing disturbance around the Stanage Edge area. Factors outside the PDNP are also important, with some birds being lost to illegal hunting along their migration route, and habitat loss due to juniper forest damage in their wintering grounds.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Warmer summers may have negative effects on ring ouzel populations. Rising temperatures have been correlated with range contractions from low altitudes in European ring ouzel, and could already be affecting PDNP populations. This would reduce the amount of suitable habitat in the PDNP, restricting them to higher crags and moorland only. This could be particularly devastating if the Eastern Moors become unsuitable, as they currently contain the largest ring ouzel population in the PDNP. Phenological mismatch has been suggested as the cause of poor ring ouzel performance following warmer summers elsewhere in Europe. A correlation between warm summers and a decline in territory the following year has been found to exist irrespective of summer rainfall. While the cause is unclear, it may be related to a mismatch in earthworm availability. This effect could extend to the PDNP population as temperatures rise. **[H]** An increase in spring and summer drought could increase this effect by reducing invertebrate prey availability. Soil and ground invertebrates, especially earthworms, are sensitive to dry ground conditions, reducing in abundance and moving deeper into the soil column. This reduction in food resource during the breeding season would result in decreased breeding success in ring ouzel. **[M]**

Human behaviour change

Hotter drier summers are likely to increase visitor numbers to the PDNP, also increasing the risk of disturbance to breeding ring ouzel. PDNP ring ouzels are known to have significantly better nesting success when disturbance is at a minimum. Therefore, rising numbers of rock climbers and other visitors could decrease nesting success significantly. **[H]**

Changes in conditions in the PDNP will prompt changes in human land use. While this effect in unpredictable, any increase in management intensity may have negative effects on ring ouzel populations. Birds nesting in heather may be particularly at risk from overstocking or increased burning. **[M]** Higher grazing pressure on heather moorland would increase nutrient loading and erosion, changing the character of the heathland. These changes to the habitat mosaic may result in reduced occupancy and breeding success in ring ouzel. **[H]**

An increase in climate change mitigation may disadvantage PDNP ring ouzel populations via habitat loss. Afforestation is a popular carbon capture method but can remove ring ouzel habitat by replacing the upland heather stands preferred for ground nests. Afforestation is likely to be more popular in steep gullies due to natural flood management benefits, these gullies being good ring ouzel habitat. **[M]**

Other indirect climate change impacts

While drier summers may not be the most significant factor affecting breeding success, reduced availability of ripe fruit and berries during late summer and autumn would reduce pre-migration condition in ring ouzel. Changes to rainfall in North African wintering grounds may also affect ring ouzel populations. Reduced occupancy in ring ouzel has been shown to occur 24 months after wet springs in Morocco, probably due to effects on juniper flowering. Therefore, changes in rainfall may increase ring ouzel migration fatalities and result in poorer post-migration condition. **[H]**

In the PDNP, wetter winters and flooding may increase waterlogging of soils, disadvantaging sensitive species such as heather in affected areas. This would not only reduce suitable nesting habitat but could also create bare ground for invasive plant species to move in and dominate. **[H]**

Increased atmospheric carbon dioxide concentrations and higher temperatures may cause increased plant growth and biomass on heathlands. Combined with dry ground conditions and drought, this may lead to an increased incidence of wildfire, especially on dry heather moorland. Wildfire leads to habitat loss and may destroy nests for those ring ouzels not nesting in rock crevices. Wildfire also has negative effects on earthworm and other ground invertebrate populations. **[L]**

Invasive or other species interactions

Warmer wetter conditions in winter may lead to increased prevalence of diseases and pest species. Bilberry are susceptible to Phytophthora, incidence of which may increase as conditions become more suitable for its spread. Bilberries are a vital autumn food resource, so reduced extent and fruiting would have a significant impact. A reduction in food availability during the weeks leading to migration would result in greater migration fatality. **[M]**

Increased annual average temperatures may lead to increased winter survival of small mammals such as weasels and stoats. This may cause decreased survival of ring ouzel nestlings and fledglings. However, warmer winters may also increase populations of preferred prey such as rabbits, reducing predation pressure on ring ouzel. **[L]**

Higher concentrations of carbon dioxide and other greenhouse gases may lead to an increase in plant growth rate, decreasing ring ouzel nesting success. A taller sward height could reduce access to invertebrates for foraging, and scrub encroachment would result in less preferable nesting habitat. However, some encroachment of scrub may be beneficial for ring ouzel as part of a habitat mosaic, providing berries in late summer and higher soil invertebrate abundance. **[L]**

Sedimentation or erosion

An increase in winter rainfall and summer storm events would result in increased runoff and soil erosion on heathland. Soil and peat on much heather moorland in the PDNP is already relatively thin, meaning that soil erosion can cause significant root damage to heather. Some nesting habitat may therefore be lost, and the habitat mosaic altered. **[H]**

What is the adaptive capacity of ring ouzel? *[Overall adaptive capacity rating: Low]*

Ring ouzel have significant barriers to adaptation to future climate change. Ring ouzel in the PDNP are at the south-eastern limit of their UK breeding range, meaning that any northward shift in their climate space is likely to cause their loss from the PDNP. Modelled shifts in habitat suitability show this loss to occur by the late 21st century. Ring ouzel in southern Europe have different habitat requirements and habits, but these are separate sub-species and there is no evidence of gene flow with UK populations. **[H]**

However, ring ouzel do have some capacity for population recovery. As migratory birds, their dispersal ability is potentially good, although they are faithful to nesting sites. Ring ouzel are long lived, allowing some scope for recovery from low breeding success if conditions improve. However, this also means ring ouzel are unlikely to have high evolutionary capacity or behavioural adaptation. European sub-species could in theory assist with recovery and adaptation, but this seems unlikely, as there is little evidence of genetic admixture. **[L]**

More information is needed to manage for ring ouzel effectively. Many of the causes of decline are not well understood, and probably relate to factors such as migration routes and wintering grounds. Reducing human disturbance at breeding sites appears to help, but this alone is unlikely to offset climate effects. **[M]**

Some financial resources may be available to build resilience of the ring ouzel in the form of environmental land management schemes. However, these are limited and in many cases there are barriers to implementation. It is also impossible to predict how these will change over the coming years, and they are especially uncertain at present. **[L]**

Institutional support would assist ring ouzel adaptation. Many of the current ring ouzel population centres are managed by conservation organisations, such as the Eastern Moors and Dove Stone Partnerships. However, the Eastern Moors population is on the edge of ring ouzel range latitudinally and altitudinally, so the value of this stronghold may decrease in the future. Ring ouzel are also a red listed bird species in the UK, a status that may increase the chances of adaptation management occurring. **[M]**

Key adaptation recommendations for ring ouzel:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Non-native upland forestry plantations remove good ring ouzel habitat and should be phased out where they are impacting ring ouzel populations.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Manage visitor access and disturbance during sensitive breeding season will increase ring ouzel breeding success, and thus help reduce non-climate related pressures.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

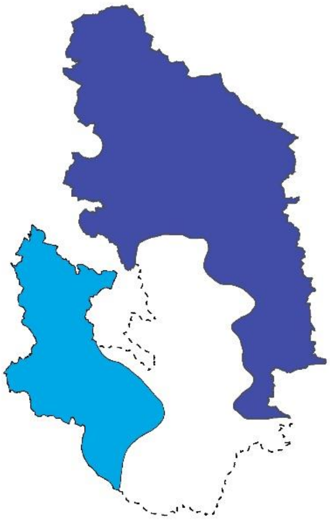
The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Move towards a habitat mosaic for ring ouzel. This includes open areas and heterogeneous vegetation structure, with some scrub in appropriate areas.
- Appropriate cutting or grazing to create varied vegetation structure would be beneficial to ring ouzel and reduce wildfire risk.

Short-eared owl

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High



Feature assessed:

- Short-eared owl (*Asio flammeus*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The short-eared owl is a charismatic moorland bird of prey, breeding in the PDNP each year before migrating to lowland and coastal wintering grounds. One of the most widespread owl species in the world, the short-eared owl breeds from South America to Russia. However, the PDNP represents the southern edge of their UK breeding range. One of the most active UK owls in daylight, short-eared owl can easily be seen on their hunts for voles and other small mammals due to their relatively large size and pale brown body. Within the PDNP, moorland in the Dark and South West Peak is preferred habitat, where they nest in scrapes on the ground. Short-eared owl are a conservation priority in the UK and Europe. As a bird of prey, they are a good indicator of ecosystems with robust prey populations.

How vulnerable are short-eared owls?

Short-eared owl in the PDNP have been rated ‘high’ on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a poor but recovering current condition, and a moderate adaptive capacity.

Short-eared owl populations in the PDNP appear to be recovering from historical decline despite continuing threats. Climate change effects on their small mammal prey may have a significant impact on short-eared owls. They are a widespread and mobile migrant, so short-eared owls are quite adaptable to changing conditions. However, this may include moving out of the PDNP. Conservation actions taken in the PDNP could assist short-eared owls in adapting to changing conditions.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Short-eared owl are in long-term decline across the UK, with an almost 50% contraction in range in the past 50 years. This trend appears to have been reversed in the PDNP in recent years, with the 2004 Moorland for the Future Breeding Bird Survey showing an increase in short-eared owl abundance and territory. 15 or more pairs were estimated to be nesting in the PDNP in 2018. Short-eared owls do not appear to be overly disadvantaged by other species interactions. Foxes, or more likely dogs, may disturb and occasionally injure a bird, especially during nesting season. Other birds of prey such as harriers and other owl species may compete with short-eared owls for prey resources but the impact of this is probably minimal.

Human land use is the most important limiting factor for short-eared owl numbers. Sheep grazing has been shown to negatively affect vole abundance, with both vole numbers approximately doubling under reduced grazing. Purple moor-grass grassland is good vole habitat, but is uneconomic and of low conservation value, so is being lost to other habitat types. Illegal persecution of short-eared owls does occur, and because they are active in daylight, they are easy to spot and kill. As an apex predator only a few need to be killed to have a large impact on populations. Wildfire is also an issue, affecting both heather and purple moor-grass moorland, removing habitat and destroying nests.

What are the potential impacts of climate change? *[Overall potential impact rating: HIGH]*

Direct impacts of climate change

Increased annual average temperatures may be beneficial to short-eared owls in the PDNP in the short term, but could result in their loss in the longer term. Milder winters may mean greater survival at their wintering grounds, as well as shorter migration distances due to closer suitable conditions. Better owl condition after return from migration could also increase breeding success. However, these benefits may eventually be lost, as suitable climate space is predicted to shift northwards. Short-eared owl in the PDNP are at the southern edge of their UK range in the PDNP and modelling suggests this may result in their loss. **[M]**

Increased winter rainfall may be detrimental to short-eared owl populations. European owl breeding success is known to be sensitive to wet winters, with higher breeding probability and larger clutch size resulting from colder and drier winters. As winters are predicted to become wetter and warmer, this may reduce short-eared owl breeding success and reduce population replenishment. **[L]** An increase in the frequency and intensity of storm events could compound this effect, as ground nesting birds are often sensitive to heavy rainfall during nesting. **[L]**

Increased concentrations of atmospheric carbon dioxide coupled with increased temperatures may lead to an increased plant growth rate in some areas. This could be beneficial to short-eared owl populations by increasing habitat suitability. Vole populations may increase as rank vegetation increases and grassland expands, and short-eared owls will have a greater access to nesting materials. **[L]**

Human behaviour change

Changes in human behaviour and land use have the potential to negatively affect short-eared owl in the PDNP. As the climate changes, suitability of some parts of the PDNP for different management types will change, leading to an unpredictable human response. If agricultural ‘improvement’ of moorland fringe grassland becomes more viable, this could result in feeding habitat loss and therefore displacement or population decline. Changes to grouse moor management may also be important; if grouse populations decline as a result of environmental change, an increase in management intensity may result. **[M]**

Construction of coastal flood defences and hard barriers may reduce short-eared owl populations by degradation and removal of their coastal wintering habitats, except where these create large areas of new habitat. As seas levels rise, management interventions such as these may become more common. Hard barriers will prevent habitat moving with sea level rise, resulting in squeezing of current habitat. Some wintering locations may therefore be lost to the sea, and saltification may affect some of the remaining habitats. This would increase competition and reduce the suitability of coastal wintering grounds, reducing short-eared owl wintering survival and condition upon return from migration. **[L]**

Other indirect climate change impacts

Short-eared owl populations fluctuate with the populations of their vole prey. As climate change places additional stressors on voles, these fluctuations may become more pronounced. Rainfall and soil moisture changes have a significant effect on voles, and extreme events can severely reduce juvenile survival. The increased variability in annual conditions may therefore cause both vole and short-eared owl populations to become more variable. **[M]**

Hotter, drier conditions during the summer months may effect an increase in wildfire in the PDNP. The resulting habitat loss and nest destruction would cause decreased breeding success in short-eared owl. Purple moor-grass moorland is very susceptible to wildfire blazes during drought, meaning that good short-eared owl habitat is some of the most at risk from this damage. **[L]**

Invasive or other species interactions

Warmer winters may increase survival of generalist predators such as red fox. Increased annual average temperatures may lead to a greater prevalence of short-eared owl diseases and pests. This would result in reduced survival of short-eared owls. **[L]** This could also affect their vole prey. As vole numbers fluctuate cyclically, disease outbreaks or extreme weather could compound the population lows, causing poor vole years to decrease short-eared owl fitness even further. **[L]**

Sedimentation or erosion

Sea level rise may cause increased erosion on short-eared owl wintering grounds, reducing wintering survival. Erosive forces may change coastal habitats by removing and redepositing sediment, and changing substrate structure. This change in substrate structure may reduce invertebrate abundance and vegetation communities and therefore the abundance or availability of prey. Habitat loss and reduction in prey populations combined could affect short-eared owls over winter, lowering survival rates and resulting in poorer condition upon return from migration. **[L]**

What is the adaptive capacity of short-eared owls? *[Overall adaptive capacity rating: MODERATE]*

Short-eared owl in the PDNP have low overall capacity for recovery from loss. The population is relatively small, with a low breeding success, meaning population growth is slow. However, short-eared owl have a large population across Europe, which could bolster a declining population. Winter migrants are present in many places further south, so there are likely to be some short-eared owl in the PDNP during winter even if the breeding population is lost. **[L]** The short-eared owl's status as a small mammal specialist on moorland may also provide some barrier to recovery, as they are heavily dependent on a specific set of food resources. **[VH]**

As a widespread migratory bird, short-eared owl have few barriers to movement. They are nomadic, and move within the UK and between the UK and Europe. In the PDNP population, the number of migrating birds and their destinations are unknown, but it is likely that migrants can provide some input to the population. The high dispersal ability of short-eared owl means that they are likely to be able to move as a response to climate change. This could result in the South West Peak population moving to the Dark Peak, or short-eared owls moving out of the PDNP entirely. **[M]**

Some funding is available to assist short-eared owl adaptation, at least indirectly. Moorland restoration projects which may benefit short-eared owls by reducing the impacts of climate change on their habitat, already exist in the PDNP. **[M]**

Institutional and organisational support can help support short-eared owl populations in the PDNP. The Peak District Birds of Prey Initiative was designed to involve partners in increasing bird of prey populations and reducing illegal persecution, targeting several species including short-eared owl. However, the project has generally failed to meet its own targets, and its future looks uncertain. Other projects such as the RSPB's Upland Skies partnership may able to provide a complementary role through public and landowner engagement. The South Pennine Moors Special Protection Area (SPA) is designated for bird species including short-eared owl, and so provides some level of protection. Short-eared owl are an amber listed bird species in the UK and are protected under the Wildlife and Countryside Act 1981. **[M]**

Management options are available in the PDNP for short-eared owl, mostly though sensitive management of the moorland habitats they depend on. However, detailed information on the migration habits, nesting areas, and breeding success of these birds are unknown, meaning it is difficult to identify and respond to changes in short-eared owl populations. **[M]**

Key adaptation recommendations for short-eared owls:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- A greater focus on bird of prey persecution is needed.
- Lower sheep grazing densities in short-eared owl habitat could benefit owl populations by increasing the populations of their small mammal prey.
- Study into migration habits of short-eared owl could clarify the resident status of PDNP birds, informing management.
- Partnership approach with coastal wintering grounds would be beneficial to short-eared owl conservation.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

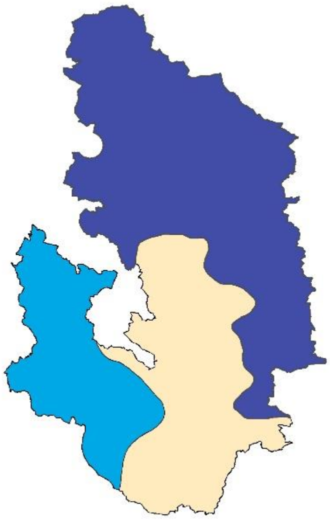
- Monitoring of known breeding pairs could increase the information resource available.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Snipe

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Snipe (*Gallinago gallinago*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

The snipe is a small streaked brown wader found year round in the PDNP. Some breed here during the spring and summer, and more migrate in from further north during the winter. It is recognised by its long straight bill, which it uses to probe the ground for invertebrates. It is easiest to spot on spring mornings, when males perform their characteristic 'drumming', flying up high and using their tail feathers to produce a loud throbbing call. Known as a farmland wader, snipe can often be found on in-bye land as well as open moor and wetter areas across the PDNP. Snipe are an amber listed species, and a priority species for the PDNP due to their national decline.

How vulnerable are snipe?

Snipe in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but with a recovering current condition and a moderate adaptive capacity.

Snipe populations in the PDNP appear to be increasing and recovering from historical losses. Changes in ground conditions will likely have the biggest impact on snipe populations: both dry and waterlogged conditions will restrict access to their invertebrate prey. These effects will be particularly important during nesting season. Snipe in the PDNP mainly breed in very specific habitat, but have the potential to adapt to changing conditions. Money available through environmental land management schemes, as well as support from conservation organisations will assist greatly with snipe adaptive capacity.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

Snipe have undergone historic decline in the UK, but numbers have recovered more recently, with a 32% national increase since 1995. In the PDNP, snipe appear to be faring better than the national average with significant increase since 1990 However, these increases are from a very low population base, and survey results vary. Snipe are difficult to detect during the daytime due to their reclusive nature, and so are often under-recorded.

Land use changes have been the leading factor in historic population reductions, and continue to have an impact on their recovery. Drainage disadvantages snipe by removing the wet flushes used for feeding and nesting. Agricultural 'improvement' of grassland also has a negative effect, as snipe require a heterogeneous grass sward, generally short but with taller areas for cover and nesting. As ground nesting birds, snipe are particularly sensitive to trampling. A grazing pressure of 2.5 cows per hectare accounts for the trampling of around 60% of nests. Heavy stocking also causes soil compaction, reducing food availability by making soil probing more difficult. High populations of generalist predators such as foxes and carrion crows on farmland can also decrease breeding success.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Hotter drier summers, especially drought periods, will cause drying out of topsoil in the PDNP. This causes invertebrate prey to move downwards, as well as hardening the ground to make probing more difficult. This reduced food availability will not only have an effect on snipe survival, but also breeding success. Their nesting season ends when soil penetration resistance rises above a threshold, meaning that earlier dry conditions in summer may restrict snipe nesting dates and allow fewer chances for re-nesting after clutch failure. An increase in extreme summer storms will only enhance this effect by increasing soil compaction by livestock trampling. **[H]**

Increased flood events are also likely to reduce snipe numbers. Earthworm abundance is reduced during flooding due to ground compaction and waterlogging, meaning their main prey is less available. Spring flooding also delays nesting dates, meaning fewer successful broods and fewer re-nesting opportunities. **[H]**

Invasive or other species interactions

Increased atmospheric carbon dioxide along with nitrogen deposition due to increased winter rainfall and summer storm events, combined with a longer growing season due to increased average annual temperatures, may act to increase the growth rate of grasses. This is likely to increase the sward height in grasslands, reducing their suitability as snipe habitat. A taller sward would cause snipe greater difficulty in moving and feeding, and reduce their ability to spot approaching danger. Chicks will also be in danger of becoming soaked and unable to dry out in the wetter microclimate of the tall sward understory. Alternatively, increased stocking could be brought in to control and make use of the greater grass growth. This would increase soil compaction and trampling. **[M]**

Increased annual average temperatures may lead to an increase in the numbers of generalist predators such as foxes and carrion crows. This could increase nest predation pressure on snipe, reducing breeding success. Studies show that some nest predation is not significantly harmful to snipe populations, but once a threshold has been passed, it can have severe effects. Therefore, as some areas pass the critical threshold for predator density snipe could decline suddenly. **[L]**

Human behaviour change

Hotter drier summers may attract more visitors to the PDNP. This has the potential to increase disturbance of nesting birds, especially by those visitors with dogs. Nest trampling may also increase, but as snipe nest away from paths this is unlikely to be a large effect. As a result, snipe may be pushed out of some popular sites. As snipe are faithful to a single site, relocation may be difficult for those birds displaced. **[L]**

Drier summer conditions and an increase in drought may act to change land use in the PDNP. Drier sites could become unsuitable for livestock during the summer months, increasing the pressure on the wetter sites that are preferred by snipe. This would lead to increased disturbance and nest trampling, decreasing breeding success. **[L]**

As climate change advances, human mitigation efforts will also increase. In the PDNP this may take the form of moorland and bog rewetting for carbon sequestration. An increase in floods associated with greater winter rainfall and more frequent summer storms may also promote natural flood management, such as upland drainage blocking. This would create new habitat and increase the suitability of some existing habitat as new wet flushes are created and vegetation heterogeneity increases. Snipe could then increase in abundance and spread into the new habitat, albeit slowly. **[L]**

Nutrient changes or environmental contamination

Increased winter rainfall and severity of summer storms may lead to increased runoff from agricultural land, washing greater levels of agrochemicals into snipe habitat. Fertilisers could facilitate an unsuitable sward height and pesticides could reduce abundance of invertebrate prey. Taken together, this would reduce the suitability of some snipe habitat, and so reduce snipe fitness and breeding success. **[L]**

Sedimentation or erosion

An increase in the frequency and severity of summer storms may increase soil erosion, especially on dry soils after drought. This erosion could affect the soil invertebrate community, reducing abundance or changing the species assemblage to favour those less preferred by snipe. Sedimentation in the wet flushes that snipe prefer could also negatively affect the soil invertebrate community. **[L]**

Other indirect climate change impacts

Hotter drier summers in the PDNP are likely to increase the frequency and intensity of wildfire. As ground nesting birds, snipe are particularly vulnerable to habitat and nest loss. An increase in wildfire would therefore reduce breeding success by increasing nest failure as well as reduce snipe populations by destroying habitat. This would mostly affect birds nesting on upland moorland, as in-bye land and rush pasture are unlikely to be affected by wildfire. **[L]**

Warmer winter conditions may have a positive effect on snipe by reducing the amount of time ground is frozen. Frozen ground prevents snipe from feeding, as penetration is more difficult and soil invertebrates such as earthworms move deeper into the soil. Ground frozen less often, and over a smaller area, would mean snipe are able to feed more easily and in more sites. Wintering survival of resident birds would be increased, and a greater number of migrant birds could utilise the PDNP. **[M]**

What is the adaptive capacity of snipe? *[Overall adaptive capacity rating: MODERATE]*

Snipe habitat has variable connectivity. Although snipe can nest in multiple habitat types including moorland, in-bye land, and rush pasture, even within these habitats they are restricted to specific areas with suitable wetness and vegetation heterogeneity. Moorland is well connected across the PDNP, but much of it is poor as snipe habitat. In-bye land has suitable habitat but is again restricted, and connectivity is generally broken by large areas of drier pastureland. As snipe are faithful to a single site, even when suitable habitat is available colonisation and expansion are slow processes. **[M]**

Snipe are slow to recover generally, but are able to tolerate a range of conditions. Because snipe pairs are site faithful, range expansion is slow, and once habitat is lost pairs find re-nesting difficult. A recovering population nationally means that the PDNP population can be bolstered by populations elsewhere. Winter migrants could also provide some birds to the PDNP population. Although the PDNP population breeds almost exclusively in lowland soft rush stands, populations in Iceland and Scotland breed on dry heath and grassland and so there is some potential for snipe habits to adapt, especially if these habitats become wetter. A large part of snipe diet is earthworms and fly larvae, and young are fed almost exclusively on earthworms. However, snipe will eat a variety of invertebrates, including some non-soil invertebrates and occasionally vegetative matter – meaning they do have some capacity to adapt to changing food sources. **[M]**

Some money is available for snipe conservation in the PDNP, increasing their adaptive capacity. Many environmental land management schemes focus on farmland waders including snipe. These schemes have been shown to be effective for farmland birds across Europe, or at worst not harmful. Snipe benefit from these schemes more than some other species. However, it is questionable whether these schemes are effectively implemented, and it is very difficult to predict how they will change in the future. **[L]**

Institutional support is available for snipe and will be important in their conservation. Projects across the PDNP such as the now defunct PDNPA Wader Recovery Project and the current South West Peak Partnership project Working for Waders aim to protect farmland waders, but have had mixed success. Much snipe habitat will lie within Site of Special Scientific Interest (SSSI) designation, although they are not specifically mentioned in the Dark Peak SSSI citation. Snipe are listed as Locally Important by the PDNPA and are an Amber List species nationally. **[VH]**

Management for snipe populations is relatively well tested. Snipe are quite well studied, although not quite as much as other farmland waders such as curlew and lapwing. Management for snipe has been a PDNP priority for over 10 years, and so management practices have had time for refinement. Predator fencing and nest protection have shown mixed success, with large gains in some areas but declines across others, indicating some gaps in knowledge. **[VH]**

Key adaptation recommendations for snipe:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Remove drains in pastureland to promote wet flushes and rush areas – by creating better habitat for snipe their current status can be improved and so they are likely to be more resilient to change.
- Rush management should be planned with the needs of different species in mind, some suitable areas of long rushes should be left intact.
- Cease the ploughing of fields and reduce chemical inputs to improve soil invertebrate populations and diversity – giving snipe a more abundant and wider choice of food.
- Predator control could be a useful tool in high predator density areas, but may inadvertently increase predator populations and disrupt other species interactions. Research is needed to determine if a more natural system would be a better option for the future.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Stocking levels should be kept low to reduce nest trampling and disturbance.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

- Ditches and other varied surface topography can provide damp areas for snipe to feed in dry periods, so these should be considered in management and development plans.

Adapt land use for future conditions

These recommendations are adaptations to the way in which people use the land. Flexibility in land management - reacting to or pre-empting changes caused by the future climate - should afford this feature a better chance of persisting.

- Prolonging high soil moisture into summer will extend the nesting season and increase snipe breeding success. Landscape scale management plans should look at interventions which can reduce the drying effect of hotter, drier summers.

Swallow

Overall vulnerability rating:

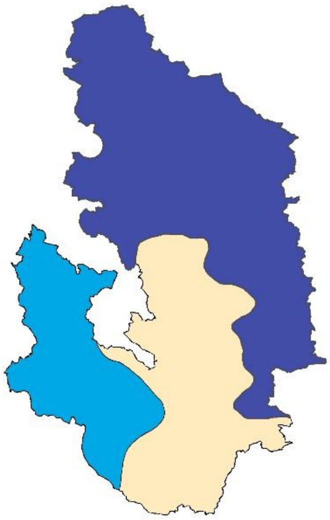
Very low	Low	Moderate	High	Very High

Feature assessed:

- Swallow (*Hirundo rustica*)

Special qualities:

- Internationally important and locally distinctive wildlife and habitats



Feature description:

Swallows are common summer migrants to the PDNP and the rest of the UK. Overwintering in Africa, swallows return to the UK to breed in spring and early summer. Agile flyers, they take insects on the wing and can be confused with other summer visitors, including related martins and the unrelated swift. However, with a good view swallows are easily distinguished by their characteristic red throat patch and long forked tail. Common birds on farmland, they are mostly found on meadows and pasture in the PDNP, and can often be found nesting in the eaves of nearby buildings. While they are still common in the UK, they have suffered losses in some parts of the country. As a charismatic farmland bird associated with summer, they are a favourite of many around the PDNP.

How vulnerable are swallows?

Swallows in the PDNP have been rated 'moderate' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, but with a reasonable current condition and a high adaptive capacity.

PDNP swallow populations appear to be faring well despite some recent losses. Drier conditions restricting nest building are likely to be leading stressors on future swallow populations. Changes to their wintering grounds may also have strong effects that are more difficult to address. Despite their low conservation priority and restricted funding and support, swallows have shown themselves to be very adaptable birds, already showing some adaptation to climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: HIGH

Current condition:

Swallows are common across the UK, with the population showing a slight increase since the 1990s. However, this trend varies by area. In the PDNP, swallow populations peaked around 2014 and have declined since, but are still higher than they were in the 1990s. Swallows may already be responding to climate change in their phenology, with migration dates advancing by 15 days and breeding by 11 days across the UK since the 1960s.

Swallows suffer from parasites such as mites and lice, especially in those individuals with low immune responses. Parasite infection reduces tail length, and so longer tailed males and their offspring tend to be more resistant to parasites. Swallows have few natural predators, but some birds of prey such as hobbies and sparrowhawks are able to take them on the wing.

Swallows are strongly linked to human development, with older buildings providing many of their nesting sites, and agricultural land providing most of their current habitat. They are therefore strongly linked to changes in human land use. Fewer available open spaces in newer buildings and loss of some older buildings have reduced nesting opportunities. The type of agricultural land is also important: Pastureland is better habitat than arable, and cow pasture is better than sheep. As such, the move towards sheep farming in the UK has probably been detrimental to swallows. Pesticide use on agricultural land is also thought to have played a large role in swallow decline. Worming agents and antibiotics in livestock are a particular problem as they reduce larvae populations in dung, thereby lowering flying insect abundance and reducing food availability for swallows significantly.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Drier conditions during summer are likely to have a detrimental effect on swallow nesting. Loss of some drinking resources, especially in the White Peak where surface water is already rare, would increase swallow dehydration and hyperthermia. Drier ground conditions could also mean fewer areas of soft ground and mud required to build nests. This may result in smaller nests of lower quality, leading to reduced clutch sizes and egg and nestling losses from fallen nests. **[H]**

An increase in extreme and unpredictable weather events may reduce swallow survival and breeding success. Swallows require fair weather conditions as their insect prey will not fly in adverse weather. Late cold snaps and snowfall during or just after swallow arrival will likely have the greatest effect, as swallow condition is already poor from migration. More frequent and severe summer storm events could cause reduced survival, as both swallows and their prey are unlikely to fly. Similarly, extended summer drought periods would reduce insect prey populations and therefore swallows. **[M]**

Sea level rise may have a detrimental effect on PDNP swallows on migration. Swallows gather to roost in UK wetlands before migrating south. Sea level rise is likely to remove some of this habitat and reduce the suitability of that remaining through saltification and increased competition. The loss of these habitats and their associated food supply would result in poorer swallow condition before migration, causing greater migration mortality. **[L]**

Higher temperatures earlier in the year will continue to advance swallow migration dates. Swallows have already begun to adjust to their migration dates more than other migrants do, and so may adjust well to future changes. As leaf bud burst and insect population maximums are advancing with climate change, any phenological mismatch will likely be minimal, especially compared to other less flexible migrants. More time in the UK would also allow more swallow broods in one year and a greater time between broods, potentially increasing breeding success. However, male and female arrival dates are already beginning to diverge, with males arriving a week earlier than females. This may limit the ability of swallows to advance their nesting date, as the females appear to be less adaptable in migration timings. **[H]**

Increased average annual temperatures may have positive effects for swallows. Warm conditions will likely mean reduced thermoregulatory costs for both adults and nestlings, increasing survival. Nest sites are also more likely to be outdoors, meaning swallows could become less dependent on buildings and other man-made sites. Warmer conditions during the breeding season may increase the flight activity of their insect prey, resulting in greater food availability. This is particularly important as female swallows form eggs from their daily diet rather than fat reserves. Therefore, food availability has a direct link to clutch size and egg quality. However, this effect could be reversed, as drier conditions may eventually result in reduced insect populations. Higher temperatures also result in increased insect flight agility, potentially increasing the difficulty of swallow foraging. This may lead to adaptation in the form of shorter tail length, as has been seen in Spanish swallow populations. **[M]**

Other indirect climate change impacts

Changes to their African wintering grounds pose a significant threat. Altered precipitation patterns are likely to have the largest effect, as swallow winter survival is strongly correlated with high rainfall on wintering grounds. Predicted rainfall change is variable across the wintering grounds and so swallow populations may be affected differentially. Those birds that migrate overland are more likely to be negatively affected, as drought is more likely inland. Desertification could also create a barrier to migration as the Sahara and Kalahari expand. Those that take a coastal route will probably be better off. As some wintering grounds become less suitable, the competition at those remaining will also increase. An increase in frequency and severity of storms would also be damaging to swallows, especially during migration. Overall, it is likely that swallow migration fitness will be reduced, increasing migration fatalities and reducing breeding success. **[H]**

Invasive or other species interactions

Increased average annual temperatures and drier conditions may result in greater parasite and disease prevalence. Swallows often carry parasites with few effects, but are more susceptible when in poor condition. Parasite and disease spread is increased during migration, when swallows travel in large, close groups. As swallows may already be stressed by changing conditions and extreme weather events, increased parasite load may exacerbate their poor condition and cause increased mortality. **[M]**

Nutrient changes or environmental contamination

Increased annual average temperatures may lead to increased agricultural pest populations. Pesticide usage may increase to counter this effect, particularly on new arable land. This would lead to a subsequent reduction in insect prey availability for swallows foraging on agricultural land. Swallows would therefore spend more time foraging and be in poorer condition. Pesticides may also bio-accumulate in swallows, causing a direct reduction in condition and breeding success. **[M]**

Human behaviour change

Hotter drier summers may result in changes to agricultural practices in the PDNP. As most PDNP swallow habitat is pastureland, these changes could be damaging to swallow populations. Abandonment of some drier sites could be detrimental as scrub and woodland is poor swallow habitat. Loss of hay meadows to pasture or abandonment or conversion to arable could also reduce swallow populations, as meadow insect populations are higher than most agricultural land. **[M]**

What is the adaptive capacity of swallows? ***[Overall adaptive capacity rating: HIGH]***

Swallows have few barriers to movement and dispersal. A highly aerial species, they are able to travel large distances and so can easily disperse and colonise new areas. This is evidenced by their large range throughout the UK and further south in Europe. The PDNP is well within swallow climatic envelope with much suitable habitat, and so swallows are unlikely to move out of the PDNP boundary. **[H]**

Swallows are a very adaptable bird. Their large population and ability to breed several times a year allows a good capacity to recover from bad conditions in the previous year. Swallows feed on a variety of aerial insects as well as some terrestrial, and so can adapt to some changes in prey abundance by utilising other prey species. Swallows have already shown adaptive ability in their response to climate change, with Spanish populations exhibiting reduced tail length and UK populations advancing in migration and egg laying date. **[H]**

Some funding is available for swallow conservation, but this is limited as they are not a conservation priority. Swallow populations may benefit from environmental land management schemes on pastureland, as insect populations increase with better management. **[M]**

Some institutional support exists for swallows. Some swallow habitat will be protected by Site of Special Scientific Interest (SSSI) designation in the PNDP, but swallows are not a cited feature of these. Swallow nests have legal protection when active under the Wildlife and Countryside Act. As they are a green listed species in the UK, swallows are seen as low conservation priority. **[H]**

Swallows are generally well researched worldwide as a migratory species with a large range. Extensive monitoring of UK migration patterns is ongoing and will enable management decisions to be well informed. **[M]**

Key adaptation recommendations for swallows:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Reduced pesticide input to livestock on pastureland. This would increase populations of swallows and other birds, as well as associated soil health benefits.
- Transition lowland pasture in the White Peak from sheep to suckler cattle, to improve insect populations.
- Ensure planning decisions leave some swallow nesting space in buildings by allowing access. Platforms with bags to catch droppings can be built. Only a small access hole is required.
- Increase potential for swallow nests in new and restored buildings, with particular consideration for agricultural buildings.
- A whole range approach, with partnership with organisations in their African wintering grounds would be needed to maximise swallow adaptive capacity.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Better knowledge and monitoring of PDNP swallow populations would help understand whether they are declining, and where action is needed.
- A review of planning applications where swallows have been a considering factor would increase understanding of where action has been done or is needed.

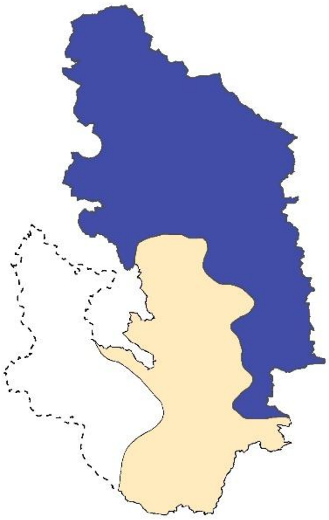
Twite

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:

- Twite (*Linaria flavirostris*)



Special qualities:

- SQ2: Internationally important and locally distinctive wildlife and habitats

Feature description:

The twite is a small brown finch with streaked brown back and breast with a pale belly. It lacks the distinctive red breast of the related linnet, but the male has a pinkish rump during summer. Generally overwintering on coastal sites in Norfolk and the South East of England, twite return in spring for the breeding season. As seed foragers, they are generally dependent on proximity to plant rich meadows. Two distinct populations of twite are present in the PDNP. One population nests in limestone quarries in the White Peak, and the rest are part of the wider moorland nesting Pennine population. The PDNP represents the south-eastern edge of the UK breeding population. However, numbers are in sharp decline across the PDNP, presenting a real risk of loss in the near future.

How vulnerable are twite?

Twite in the PDNP have been rated 'very high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a very poor current condition approaching complete loss, and a low adaptive capacity.

Twite are faring poorly in the PDNP, with moorland populations lost in many places and a small quarry dwelling population in the White Peak being the largest known colony. Climate change may cause twite to move out of the PDNP as they are on the south-eastern edge of their UK range here. Changes in flowering and seed setting timings of their plant food resources may cause a mismatch between twite nesting dates and seed abundance, and interrupt continuous food supply. Twite are a mobile species, but are unlikely to overcome future challenges presented to them. The greatest pressure will probably come from human land use change, so institutional and economic support will be needed to implement management interventions. Unfortunately, the resources currently available do not appear sufficient to retain twite in the PDNP.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: LOW

Current condition:

The twite has suffered wholesale decline across the UK in recent years, and the PDNP has been no exception. Despite having been described as a stronghold in the past, the 2004 Moorland Breeding Bird Survey found heavy population losses, showing a 92% decline in numbers since 1990. It can be assumed that twite are functionally extinct in some areas of PDNP moorland, and close to being lost from the entire area. Trends for the White Peak are less well known, but a population of around 60 birds was estimated in 2017.

Twite decline is thought to be largely due to human land use changes leading to habitat loss. The move from hay meadows to silage making has led many grasslands in the PDNP to become less diverse and cut more often, drastically reducing seed availability. Similarly, agricultural 'improvement' of grasslands on the moorland edges has led to lower seed availability - the low floristic diversity also producing less variation in seed setting times, meaning food resources are not available year-round. Feeding sites need to be within two km of the moorland edge, so good feeding sites are often too far from nesting habitat to support twite populations. High stocking levels may also have contributed to this effect by reducing the suitability of grassland. Changes to moorland nesting habitat may have also contributed, with high stocking levels and inappropriate management reducing suitability.

Twite only really established themselves in 1960s, even in 1930s with lots of available grassland they weren't very successful. Their populations fluctuate largely.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

As average temperatures increase, suitable twite climate space is likely to contract northward. Twite are a cold adapted upland species, and the PDNP is at the south-eastern edge of their UK range. As their climate envelope shifts northwards and upwards, this is likely to result in twite being lost entirely from the area. Modelling suggests this range contraction will affect much of the UK, with the only suitable habitat remaining in the late 21st century being in northern Scotland. **[M]**

Increased atmospheric carbon dioxide concentrations may change grassland community composition by favouring fast growing grass species. Compounded by a potential increase in winter nitrogen deposition due to increased rainfall, this may act to reduce the floristic diversity of grasslands, especially in uplands. This would reduce seed availability for twite by decreasing variability in flowering times, affecting breeding success. **[H]**

Changes in annual precipitation cycles may affect twite feeding grounds. An increase in winter waterlogging and summer drought can act to change the community composition, in both cases potentially reducing floristic diversity. Waterlogging could move the community composition of lowland meadows towards a wet meadow species assemblage, increasing rush dominance and likely reducing seed availability. Waterlogged soils are also at greater risk of trampling and poaching causing soil compaction. Drought will favour tolerant species and reduce diversity, but may cause greater seed production in stressed plants. Both wetter and drier grasslands are likely less suitable for twite. **[L]**

Other indirect climate change impacts

Increased annual average temperatures may change natural growth cycles, potentially driving phenological mismatch in twite. The timing of seed setting in various meadow plants are important to ensure a continuous food supply during the breeding season. Seed setting times are likely to advance with warming temperatures, meaning that twite nesting dates may have to advance to match. As migratory birds, twite are less flexible in nesting dates and so a mismatch may occur. Different plants may also adapt at different rates, breaking the continuity of seed supply. Both these effects would lead to a reduction in twite numbers and breeding success. **[H]**

Hotter summer conditions and more frequent drought will likely combine to increase the frequency and severity of wildfire, especially on heather moorland. Wildfire affects dense mature heather stands more than other vegetation types, and are the most likely to contain twite nests. This would represent both loss of preferred nesting habitat and potential nest destruction. Overall, twite nesting success will be reduced. **[H]**

Human behaviour change

Hotter drier summers may result in increased visitor numbers in the PDNP. Higher footfall would result in increased disturbance to twite at any remaining moorland nesting sites, as well as increased trampling of vegetation at feeding sites. Twite breeding success could therefore be reduced. Combined climate changes may drive changes in PDNP agriculture. It is hard to predict exactly how land use will change, but changes could easily be detrimental to twite populations. As twite are dependent on managed grasslands in the PDNP, land abandonment can reduce food resource due to scrub encroachment, while increases in stocking can reduce food resource via overgrazing. Changes in management not directly aimed at increasing floristic diversity are unlikely to be beneficial. **[M]**

An increase in the frequency and severity of summer droughts and storms may have negative consequences for twite feeding resources. Greater unpredictability of weather may drive a move away from hay meadows as grassland management. If hay meadows are replaced by grassland types with lower floristic diversity, the suitability of in-bye land for twite feeding will be even further reduced, driving population decline. **[M]**

Sea level rise is likely to drive an increase in coastal re-alignment and flood barrier development, affecting twite at their wintering grounds. This may cause a reduction in area of the saltmarsh habitat preferred by twite, squeezing the remaining habitat as the sea level rises if new habitat is not created. Competition at the remaining habitat would be increased with wintering twite from other UK sites, birds arriving from northern Europe and other bird species. Twite wintering survival could therefore be reduced. **[M]**

Climate change mitigation efforts may be detrimental to twite populations. Afforestation for carbon capture and upland wind farm development for renewable energy can both reduce the area of suitable habitat for twite. Twite within the PDNP will almost certainly be protected from wind farm development, but construction along their migration routes and coastal wind farm installations at their wintering grounds could still affect these populations. Small birds are less at risk from collision, so migration fatalities are unlikely to increase significantly. Coastal wind farms could however reduce overwintering habitat, lowing winter survival. **[L]**

Sedimentation or erosion

Coastal wintering grounds are at high risk of erosion damage. An increase in the frequency and severity of storm events, and sea level rise may act to increase erosion at preferred coastal habitats, for example saltmarsh. Pioneer communities on newly created sandbanks will be at greatest risk from erosion. As these areas are lost, competition at the remaining sites will increase. This would result in greater winter fatality in twite, and poorer condition upon return to the PDNP, causing a reduction in breeding success. **[H]**

Wetter winters and more frequent summer storms may cause an increase in soil erosion, especially on heathland where soil is already thin. This can increase root damage to heather, increasing susceptibility to winter desiccation. Loss of heather from some areas and stunted growth in others could further reduce the availability of preferred twite nesting habitat. **[H]**

Invasive or other species interactions

Increases winter nitrogen deposition due to higher rainfall may damage twite nesting habitat through its effects on heather. Excess available nitrogen causes increased susceptibility to heather beetle outbreaks, stunting growth across large areas. This could reduce heather dominance and leave areas unsuitable for nesting, as dense stands of mature heather are preferred nesting habitat. **[M]** This process may be compounded if wetter conditions are beneficial to heather beetle. Twite can use other nesting habitat such as bracken beds, which may become more common as warmer conditions prevail. However, the overall effect would probably be a reduction in suitable nesting habitat and therefore breeding success. **[H]**

Nutrient changes or environmental contamination

Warmer conditions may cause an increase in growing season in heathlands, reducing twite habitat suitability. A longer, warmer growing season would result in faster nutrient cycling, driving changes in plant community composition. Competitive species such as grasses may become more dominant, moving heather moorland towards an acid grassland assemblage. This grassland is relatively poor feeding habitat, and would replace preferred twite nesting habitat, leading to a reduction in twite breeding success. **[M]**

An increase in flooding may cause nutrient enrichment of meadows through runoff from improved grassland and arable fields. This nutrient loading of meadows would reduce floristic diversity. Less diverse meadows are poorer twite feeding habitat due to reduced seed availability, leading twite breeding success to decrease as a result. **[M]**

What is the adaptive capacity of twite? ***[Overall adaptive capacity rating: LOW]***

As migratory birds, twite can overcome some barriers to adaptation. Migration distances of up to 400 km have been recorded between wintering and breeding sites. However, most fledglings move less than five km from their natal sites, meaning their spread is relatively slow. This is exacerbated by the fragmentation of their feeding sites; hay meadows are increasingly rare both within and outside the PDNP, limiting twite site choice. Despite mixing flocks at wintering sites, twite population mixture is relatively rare. However, this does occur and can counter some of the effects of inbreeding and genetic drift in small populations. **[H]**

Twite are relatively versatile in their habits, giving them some potential to adapt to changes to their habitat. Twite can feed on a wide variety of seed, using different methods including foraging from the ground, bending seed heads, and perching on plants. However, they are exclusive seedeaters so their diet is still restricted. Twite can also potentially utilise a variety of nesting habitats including both heathland, grassland, and crevices, as evidenced by the White Peak quarry population. **[H]**

Environmental land management schemes could help improve the adaptive capacity of twite. Schemes aiming to increase floristic diversity in agricultural land adjacent to nesting areas could benefit twite populations by providing a food source to bolster the numbers of remaining birds. However, there is currently much uncertainty about the future of agricultural subsidies, and what change will mean for the future of farming in the UK. **[L]**

Some institutional support is currently available for twite, but there are limits in the practical application of beneficial management. Twite are protected under the European Union Birds Directive, and are a red listed species in the UK. They are also part of the designated upland bird assemblage for the South Pennines Special Protection Area (SPA), affording them some potential benefits. Projects such as the RSPB and Natural England Twite Recovery Project are also working to assist twite recovery. However, the scale of change that is needed, especially to agricultural land, means that the impact of these projects is limited. Effects relating to coastal wintering grounds will also be hard to address for organisations such as the PDNP. **[VH]**

Gaps in knowledge relating to twite requirements are likely to hamper efforts to make adaptations for the species. Due to a lack of research on habitat choice and causes of decline, interventions to assist twite populations may be less effective than they could be. The heavily reduced twite population currently present will also mean that future research is more difficult. **[H]**

Key adaptation recommendations for twite:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Restoration of quarries where appropriate will provide habitat for the larger White Peak population to expand into.
- Integrated management of twite nesting and feeding habitat is essential to their preservation. Co-ordinated management of upland moorland and lowland meadows will give the best chance for twite survival.
- Lowering livestock densities on pastoral land can improve its suitability as feeding habitat.
- Twite are migratory birds, so management interventions in the PDNP will have a limited effect if not part of wider efforts in wintering grounds. Partnership with coastal conservation organisations in Norfolk and the south-east coast will be the most beneficial to PDNP twite.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Loss of feeding resources is likely the biggest contributing factor to the current decline. Meadow creation will therefore be very beneficial to twite populations. Expansion of existing meadows and conversion of some improved grassland near twite nesting areas may prevent or slow the loss of twite from the PDNP.
- Develop fire contingency plans, and ensure management of habitats reduces fire risk e.g. rewetting and increasing species or structural diversity. Influence visitor and behaviour management plans and practices to minimise ignition risk.

Improve current condition to increase resilience: Increase structural diversity to improve resilience at a landscape scale

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations focus on increasing the structural diversity of the area or habitat in which the feature is found. This can help to offset the effects of climate change on the feature, as well as to allow it to be in a better position to recover from future climate changes.

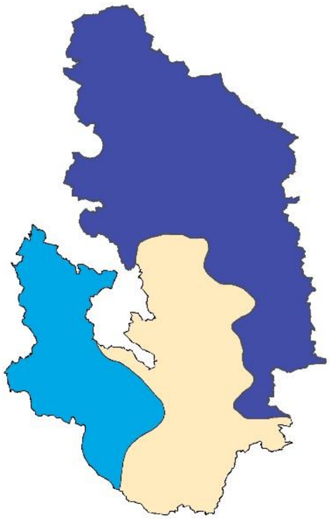
- Allow some stands of mature heather to persist within a varied vegetation structure, to allow nesting habitat while minimising wildfire risk. Rotational burning is unlikely to create this structure and so should be phased out.
- Bracken can provide nesting habitat for twite. Consider preserving bracken on steep slopes within 2km of feeding habitat where vegetation is otherwise unsuitable for nesting.

Waxcap fungi

Overall vulnerability rating:

Very low	Low	Moderate	High	Very High

Feature assessed:



- Waxcap fungi (*Hygrocybe spp.*)
- Waxcap grasslands with grassland fungi assemblages

Special qualities:

- Internationally important and locally distinctive wildlife and habitats

Feature description:

Waxcaps are a distinctively colourful group of fungi found on grazed and mown grasslands. There is a diverse assemblage in the PDNP, and grassland fungi from various groups including earthtongues, fairy clubs, and pinkgills grow alongside them in so called 'waxcap grasslands'.

Waxcaps are thought to be mycorrhizal fungi - forming a symbiotic relationship with plant roots by providing soil nutrients in exchange for organic carbon. Much of the PDNP contains grazed landscapes, and a few sites such as the Longshaw Estate are internationally recognised for grassland fungi diversity. 1081.5 hectares of waxcap grassland have been mapped, but this certainly under-records where waxcaps can be found.

Waxcaps benefit from livestock grazing and mowing, as a short grass sward benefits their fruiting bodies. Intensive management such as nitrogen fertilisation, overgrazing, and ploughing can have severe negative impacts. As such, waxcaps have been lost from many agricultural areas, but less intensively managed parkland, including estate land and churchyards, still contain some interest.

Waxcaps are a striking and characteristic feature of traditionally managed pastureland, and a sign of historical agriculture persisting. Waxcaps in the PDNP are of conservation importance in the UK, and internationally. Many sites of international, national, and regional importance have been found, and the UK British Action Plan (UK BAP) priority species the date-coloured waxcap can be found here.

How vulnerable are waxcap fungi?

Waxcaps in the PDNP have been rated 'high' on our vulnerability scale. This score is due to high sensitivity and exposure to climate change variables, with a variable and often unknown current condition, and only a moderate adaptive capacity.

Waxcap grassland condition in the PDNP is variable, with some sites of national importance, but many others unknown or under-recorded. The impact of climate change on waxcap grasslands is unclear, as they are a habitat more dependent on management than climate. One factor that will be likely to have an effect is increased nitrogen deposition, which may act to reduce the extent and abundance of waxcaps. Waxcaps are not particularly adaptable as a genus, but management knowledge and application has some potential to reduce the impact of climate change.

Overall potential impact rating: HIGH

Overall adaptive capacity rating: MODERATE

Current condition:

It is difficult to assess the current condition of waxcaps even at the national level because they are so under-recorded. Within the PDNP there are many areas that have some records, but many will also go unnoticed and unrecorded. Of the known sites, several are of national importance following Joint Nature Conservation Committee (JNCC) guidelines, with at least 19 waxcap species present. These include the Longshaw Estate, Alport Valley grasslands, Chatsworth House Lawns, Coombes Dale and Hucklow Edge.

Due to their specific habitat requirements, waxcaps are generally dependent on a narrow band of management intensity. A cessation of management will allow the grass sward to increase and disadvantage waxcap fruiting, but intensification of management will have severe negative impacts. This often occurs through ploughing of fields, which can destroy the underground hyphal networks that are the main body of the fungi. Nitrogen fertiliser application and liming also disadvantage fungi generally, and overgrazing can damage fruiting bodies and increase nitrogen enrichment through dung. As waxcap communities are slow to establish, only fields that have not seen ploughing or improvement in living memory are likely to have high waxcap interest. As a result, many fields that were once waxcap grasslands will have lost their communities as agricultural intensification became more commonplace. Waxcap communities on mown lands are also at risk as the increasingly common practice of leaving cuttings to lie increases nutrient enrichment.

What are the potential impacts of climate change? ***[Overall potential impact rating: HIGH]***

Direct impacts of climate change

Nitrogen deposition may increase as a result of greater winter rainfall. Waxcap and other macrofungal communities are sensitive to high soil nitrogen levels. The cause of this sensitivity is unclear, and likely is due to multiple effects, but is well documented in upland sites. This could lead to a loss of waxcaps from some sites, especially upland sites and those near roads. **[H]**

Hydrological changes may also affect the suitability of waxcap habitats. Some grassland may become flooded for parts of the year, waterlogging the hyphal network. Waxcaps require well-drained soils, so this could damage the hyphal network and cause the loss of waxcap communities from some sites. Drought could be more significant, drying out some sites during the summer months. This could damage hyphal networks and reduce fruiting in affected sites, causing the loss of waxcaps from some sites or slowing their growth and dispersal. **[M]**

Increased average annual temperatures may have a positive effect on waxcap fungi. Higher temperatures due to climate change are predicted to be generally beneficial for fungi, and so waxcaps may spread and fruit more often. However, dry conditions can be devastating for fungal communities, as was seen in the 2018 summer drought. Therefore, any benefit from increased temperatures could be countered by the accompanying drier summer conditions. **[M]**

Changes in annual precipitation cycles may have a large impact on waxcap populations. Fungi are dependent on high soil moisture levels, especially during the fruiting season when wetter conditions allow their fruiting bodies to last and spread spores for longer. Wetter autumn conditions may therefore benefit some fungi. As later fruiters, waxcaps could be well placed to take advantage of this - fruiting closer to the wetter winter than the drier summer. However, this could be offset by the action of summer droughts. Drier summer conditions reduce fungal growth and reduce the likelihood of fruiting. As a result, any benefits of wetter autumn conditions would be lost as fruiting bodies may not be present to take advantage of them. **[L]**

Invasive or other species interactions

Increased average annual temperatures may result in larger populations of burrowing mammals such as moles and badgers. This would result in increased disturbance of the ground in fields. In waxcap grassland, this could result in damage to the hyphal network of the soil. As the hyphal network is slow to recover from damage, this could result in some waxcaps being lost, and reduced fruiting in some sites. Increased aeration of the soil could however be beneficial. **[L]**

Increased nitrogen availability may increase the growth rate of surrounding grasses, reducing the fruiting rate of waxcaps due to the adverse microclimate created under the long sward. While the effects on the underlying hyphal network are unclear, this would lower the presence and visibility of waxcap fruiting bodies and reduce their dispersal ability. Taller grasses can also change the composition of the bryophyte layer with which some grassland fungi are thought to have a symbiotic relationship, potentially changing the fungal composition. **[L]**

Other indirect climate change impacts

Warmer winter conditions will mean fewer frost events. Early frost events have strong negative effects on fungal fruiting bodies, preventing their occurrence and causing die-off in those already present. Fewer frost events will therefore result in a greater number of fruiting bodies being produced, generating spores for longer. This would increase the visibility of waxcaps and promote their dispersal. However, the associated group of earthtongues benefit from cold weather of 3°C or lower, so overall grassland fungal diversity may be reduced. **[M]**

An increase in wildfire associated with hotter summer temperatures and droughts may be damaging to some waxcaps. Where less diverse waxcap communities are found growing in long sward purple moor-grass moorland in the Dark and South West Peak, wildfire is a significant risk. If the hyphal network is damaged by fire as it chars the soil, the fungi could take decades to recover. While the more diverse sites on pasture and estate land are unlikely to be affected by wildfire, these sites containing a few specimens are more widespread across the PDNP, and so may represent an equally large resource. **[L]**

Human behaviour change

Hydrological changes may change land use on pastureland. Some fields will become less suitable for livestock at certain times of the year due to waterlogging or drought. The grazing intensity on those fields unaffected by this could increase. Increased grazing pressure can negatively affect waxcap communities by ground compaction and trampling, as well as increase nitrogen deposition through dung. Overgrazing of fields also encourages mat grass dominance, an unsuitable sward for waxcap fruiting bodies. This disturbance, even if for only short periods, could severely damage slow to recover waxcap communities, causing a reduction in their extent. **[L]**

Nutrient changes or environmental contamination

Increased winter rainfall and severity of summer storm events may lead to greater runoff in the PDNP. This has the potential to spread fertilisers and enriched soil from more intensively farmed land onto waxcap grassland and other pastureland. This nitrogen enrichment would cause a reduction in abundance and extent of waxcap communities. **[L]**

What is the adaptive capacity of waxcap fungi? ***[Overall adaptive capacity rating: MODERATE]***

Waxcap hyphal networks grow extremely slowly, and as a result, they are difficult to recover once damaged. Once lost entirely, a waxcap community can take up to 50 years to re-establish. This is compounded by the specific management requirements for a diverse waxcap community, meaning that a beneficial management regime must be implemented for some time before results are felt. **[H]**

There are over 40 species in the waxcap assemblage, though at least 19 must be present on a site before habitat is considered waxcap grassland of national importance. Most species have broadly similar sward and drainage requirements, though soil preferences can vary in terms of acidity and composition. As a result, there is limited diversity in ecological niche within the waxcaps. However, one or two species are well adapted to disturbance and so can be found in places where others are unlikely to be, including newly created and wetter grasslands. **[H]**

Although the most important waxcap habitat covers small areas of high diversity, much of the PDNP is grassland and so has the potential for some waxcap value. Improved grassland is unlikely to contain much interest for waxcaps and allies, but some species may be present in low concentrations. This habitat has high connectivity throughout the PDNP and extends out of the boundary, so the less visible waxcap populations are likely to cover a large area. Soil genomic studies show that waxcap hyphae can be found in areas that have never had records of their presence, meaning that waxcaps may be present in many soils but only fruit occasionally or in some parts of the network. If true, changes in management could yield results quickly as a hyphal network will already be established. Connectivity is lower in parklands and lawns separated by urban areas. **[L]**

Limited financial resources are available for the conservation of waxcap grassland mostly due to lack of knowledge and awareness resulting in no specific prescription within environmental land management schemes. The economic incentive for intensive management is also greater than that for low intensity conservation management, and so uptake of any potential projects may be reduced. However, waxcaps are in a unique position in that much PDNP pastureland could be increased in ecological value with relative ease by managing for waxcaps. Waxcaps will also benefit from other changes in management to benefit soil health and sustainability. **[L]**

Some institutional support is available for waxcaps and their habitats, with sites such as Longshaw Estate having been managed for waxcap communities for decades. As recognition of the value of waxcaps in the PDNP grows, more sites may benefit from better waxcap management. Some species are recognised as UK BAP priority species, with the date-coloured waxcap a PDNP priority species. Only a few sites of high value fall within Site of Special Scientific Interest (SSSI) or Special Area of Conservation (SAC) designation, leaving many without statutory protection. **[M]**

Management techniques for waxcaps are reasonably well known, with traditional farming methods likely to be the most beneficial. Lowering grazing pressure, ceasing ploughing and tillage, and reducing chemical inputs are known to produce high value waxcap grasslands in the long term, provided a spore source is available. This management can be worked into existing land use across large areas of the PDNP with benefits to soil health and other ecological benefits. **[L]**

Key adaptation recommendations for waxcap fungi:

Improve current condition to increase resilience

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are aimed at improving the condition of the feature at present, therefore making it better able to withstand future changes to climate.

- Survey greater areas of PDNP grassland to assess true extent of waxcap grassland.
- Alter management of pastureland to increase waxcap populations. Cease ploughing and ensure appropriate grazing levels, and lower inputs of fertiliser and lime. Introduce measures to reduce compaction and waterlogging. Concurrent benefits of improved soil health and ecological condition mean this is desirable even disregarding waxcaps.
- Management of large lawns such as those on estate land should have a greater focus on waxcap assemblage.
- Promote PDNP waxcap grasslands, as they are already some of the finest internationally. An increase in awareness and knowledge may lead to wider benefits for waxcap grassland resilience and soil health.
- Encourage further uptake of environmental land management schemes by farmers within the PDNP.

Improve current condition to increase resilience: Targeted conservation efforts for important sites and at risk areas

The current condition of a feature is an important factor alongside its sensitivity and exposure, in determining its vulnerability to climate change. These recommendations are conservation measures aimed at those sites that will have the biggest impact for this feature – either because they are particularly important for the feature or because they are most at risk from climate change.

- Training on identification of CHEGD fungi (**C**lavaroids (club and coral fungi), ***H**ygrocybe spp.* (waxcaps), ***E**ntoloma spp.* (pinkgills), ***G**eoglossum* and related genera (earthtongues), and ***D**ermoloma spp.* (as well as *Porpoloma* and *Camarophyllopsis spp.*) will increase the pool of surveyors to identify and designate sites of importance.

Adaptations that could aid other features

These recommendations are changes that could be made to this feature, which will have a positive impact on the ability of other vulnerable features to withstand future climate change.

- Focus of future assessments and management should be broadened from just waxcaps to include the wider grassland fungi assemblage that associates with waxcap grassland. This is often known as the CHEGD group.

6. Glossary

Adaptation - *The way in which a species or feature can change to better suit new conditions.*

Adaptation measures - *Changes in management or other interventions to assist feature persistence.*

Adaptive capacity – *The ability of a feature to adapt to changing conditions. This includes potential human interventions to assist the feature.*

Assemblage – *The species community typical of a certain habitat.*

Below ground workings – *Mines and associated features that are below the ground, as opposed to surface workings, which include quarries and pits.*

Calaminarian grassland – *A type of grassland that develops on nutrient-poor soils with high levels of toxic heavy metals, such as zinc, lead, chromium and copper.*

Climate space – *The area in which conditions are suitable for a particular species to live. This can move as conditions change.*

Community – *The different species living together in an ecosystem.*

Community composition – *The mix of species within a community.*

Exposure – *The environmental variables a feature may be exposed to as climate conditions change. These are grouped into five categories: atmospheric pollution, temperature, precipitation, extreme events, and sea level.*

Eutrophication – *Enrichment of a habitat (particularly aquatic) with nutrients, leading to issues such as algal blooms.*

Feature – *An important quality of the PDNP, ranging from individual species to landscape scale habitats. Features that are similar have been grouped together to be considered within the same feature. 62 features are assessed in this report, often containing several component features each, and these are grouped into seven themes (see below).*

Fitness – *The ability of an individual plant or animal to survive and reproduce.*

Iron pan (soil) – *An impermeable iron rich layer found in some podzols. This can cause the soil above to become waterlogged, but is also at greater risk of drying out due to its shallow nature.*

Leaching – *The process of high levels of precipitation moving organic matter and soluble minerals further down in the soil. This leaves the leached layers deficient in those compounds.*

National Character Area (NCA) – *An area defined by Natural England that follows natural boundaries, taking into account landscape, biodiversity, geodiversity, history, and cultural and economic activity. There are 159 NCAs in England.*

Nutrient flushing – *The rapid movement of nutrients via water from one site to another. Can leave some areas nutrient poor in periods of heavy rainfall.*

Phenology – *the timing of biological events that are often related to climate. For example, flowering in plants and migration or reproduction in animals.*

Photoinhibition - *the decrease in photochemical efficiency experienced in response to intense illumination due to radiation damages.*

Podzol – *A soil type found in moorland characterised by leaching of organic matter and soluble minerals into lower soil layers. This results in a bleached layer overlying a mineral rich layer.*

Precipitation – *Any water that falls from the sky. This includes rain, hail, sleet, and snow.*

Productivity – *The rate of biomass creation of a species or habitat; how much growth occurs in a given period.*

Resilience – *The ability of a feature to persist as conditions change.*

Sensitivity – *The degree to which a feature is influenced positively or negatively by the exposure. This considers a feature's response to changing environmental conditions (see exposure for the main variables assessed).*

Shelterbelt – *A row of plants, generally trees or shrubs, that provides protection from wind to the adjacent land.*

Soil poaching – *The changes to soil structure that occur when compacted, for example under the weight of heavy animals or vehicles. Disturbance and opening up of bare ground will also occur.*

Special quality – *The special qualities define what is distinctive and significant about each National Park. There are seven special qualities of the PDNP: (1) Beautiful views created by contrasting landscapes and dramatic geology, (2) Internationally important and locally distinctive wildlife and habitats, (3) Undeveloped places of tranquillity and dark night skies within reach of millions, (4) Landscapes that tell a story of thousands of years of people, farming and industry, (5) Characteristic settlements with strong communities and traditions, (6) An inspiring space for escape, adventure, discovery and quiet reflection, and (7) Vital benefits for millions of people that flow beyond the landscape boundary.*

Succession – *The natural process of one habitat type giving way to another e.g. grassland -> scrubland -> woodland.*

Theme – *A broad theme that groups similar feature groups together. The seven themes are: (1) built environment, (2) communities, (3) cultural landscapes, (4) geology, geomorphology and soils, (5) habitats, (6) water, and (7) wildlife.*

Vernalisation – *The process by which cold winter conditions trigger plant development. Prolonged cold can trigger the germination of seeds and flowering of certain plants in the spring.*

Vulnerability – *The extent to which a feature is susceptible to damage from climate change. This is calculated based on the potential impact (exposure and sensitivity) and the adaptive capacity of the feature.*

Acronyms

CAP – Common Agricultural Policy

CHEGD group – Clavaroids (club and coral fungi), Hygrocybe spp. (waxcaps), Entoloma spp. (pinkgills), Geoglossum and related genera (earthtongues), and Dermoloma spp. (as well as Porpoloma and Camarophyllopsis spp.

CROW - The Countryside and Rights of Way Act 2000

DEFRA - Department for Environment, Food and Rural Affairs

DfT - Department for Transport

ELMS - Environmental Land Management Scheme

JNCC – Joint Nature Conservation Committee

NCA – National Character Area

NERC - Natural Environment Research Council

NERC Act 2006 – Natural Environment and Rural Communities Act 2006

NGO – Non-Governmental Organisation

NMP - National Mapping Programme

NPMP - National Park Management Plan

NVC – National Vegetation Classification

PDNP – Peak District National Park

PDNPA – Peak District National Park Authority

PDMHS - Peak District Mines Historical Society

RHS - Royal Horticultural Society

RSPB – The Royal Society for the Protection of Birds

SAC – Special Area of Conservation

SHINE - Selected Heritage Inventory for Natural England

SPA – Special Protection Area

SSSI – Site of Special Scientific Interest

UK BAP – UK Biodiversity Action Plan

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8. Scientific names

Amphibians and Reptiles

Adder (*Vipera berus*)

Great crested newt (*Triturus cristatus*)

Plants

Alder (*Alnus glutinosa*)

Alpine penny-cress (*Noccaea caerulescens*)

Ash (*Fraxinus excelsior*)

Australian Swamp Stonecrop (*see New Zealand pigmyweed*)

Beech (*Fagus sylvatica*)

Bell heather (*Erica cinerea*)

Betony (*Stachys officinalis*)

Bilberry (*Vaccinium myrtillus*)

Birch (*Betula spp.*)

Bird Cherry (*Prunus padus*)

Bird's-foot trefoil (*Lotus corniculatus*)

Bitter vetch (*Lathyrus linifolius*)

Blackthorn (*Prunus spinosa*)

Bluebell (*Hyacinthoides non-scripta*)

Bog cranberry (*Vaccinium oxycoccos*)

Bracken (*Pteridium aquilinum*)

Canadian pondweed (*Elodea canadensis*)

Clover (*Trifolium spp.*)

Common bent (*Agrostis capillaris*)

Common cotton-grass (*Eriophorum angustifolium*)

Common knapweed (*Centaurea nigra*)

Common heather (*Calluna vulgaris*)

Common nettle (*Urtica dioica*)

Common water-crowfoot (*Ranunculus aquatilis*)

Cow parsley (*Anthriscus sylvestris*)

Cowslip (*Primula veris*)

Cross-leaved heath (*Erica tetralix*)

Crowberry (*Empetrum nigrum*)

Dwarf bladder-moss (*Physcomitrium sphaericum*)

Devil’s bit scabious (*Succisa pratensis*)

Dog’s mercury (*Mercurialis perennis*)

Globeflower (*Trollius europeaus*)

Great burnett (*Sanguisorba officinalis*)

Great reedmace (*Typha latifolia*)

Greater tussock sedge (*Carex paniculata*)

Hare’s-tail cotton-grass (*Eriophorum vaginatum*)

Hawthorn (*Crataegus monogyna*)

Hazel (*Corylus avellana*)

Heath bedstraw (*Galium saxatile*)

Heath milkwort (*Polygala serpyllifolia*)

Himalayan balsam (*Impatiens glandulifera*)

Hogweed (*Heracleum sphondylium*)

Holly (*Ilex aquifolium*)

Hutchinsia (*Hornungia petraea*)

Ivy (*Hedera helix)*

Jacob’s-ladder (*Polemonium caeruleum*)

Japanese knotweed (*Fallopia japonica*)

Kingcup (*Caltha palustris*)

Lady’s mantle (*Alchemilla* spp.)

Large-leaved lime (*Tilia platyphyllos*)

Lily-of-the-valley (*Convallaria majalis*)

Marsh cinquefoil (*Comarum palustre*)

Marsh thistle (*Cirsium palustre*)

Mat grass (*Nardus stricta*)

Melancholy thistle (*Cirsium heterophyllum*)

Mountain pansy (*Viola lutea*)

Mossy saxifrage (*Saxifraga bryoides*)

Mudwort (*Limosella spp.*)

New Zealand pigmyweed (*Crassula helmsii*)

Oak (English / sessile) (*Quercus robur* / petraea)

Perennial ryegrass (*Lolium perenne*)

Pignut (*Conopodium majus*)

Pond water-crowfoot (*Ranunculus peltatus*)

Purple moor-grass (*Molinia caerulea*)

Pyramidal orchid (*Anacamptis pyramidalis*)

Pyrenean scurvy grass (*Cochlearia pyrenaica*)

Red clover (*Trifolium pratens*)

Rhododendron (*Rhododendron spp.*)

Ribwort plantain (*Plantago lanceolata*)

Rosebay willowherb (*Chamaenerion angustifolium*)

Round-leaved sundew (*Drosera rotundifolia*)

Rowan (*Sorbus aucuparia*)

Sessile oak (*Quercus petraea*)

Sheep's fescue (*Festuca ovina*)

Shoreweed (*Littorella uniflora*)

Sitka spruce (*Picea sitchensis*)

Small-leaved lime (*Tilia cordata*)

Soft rush (*Juncus effusus*)

Spring cinquefoil (*Potentilla neumanniana*)

Spring sandwort (*Minuartia verna)*

Sycamore (*Acer pseudoplatanus*)

Sphagnum mosses (*Sphagnum spp.*)

Tormentil (*Potentilla erecta*)

Water crowfoot (*Ranunculus aquatilis)*

Wavy hair-grass (*Deschampsia flexuosa*)

Wild garlic (*Allium Ursinum*)

Willow (*Salix spp.*)

Wood anemone (*Anemone nemorosa*)

Wood-sorrel (*Oxalis acetosella*)

Yellow archangel (*Lamium galeobdolon*)

Yellow rattle (*Rhinanthus minor*)

Mammals

Badger (*Meles meles*)

Cat (*Felis catus*)

Fox (*Vulpes vulpes*)

Grey squirrel (*Sciurus carolinensis*)

Hedgehog (*Erinaceus europaeus*)

Mink (Neovision vision)

Mountain hare (*Lepus timidus*)

Otter (*Lutra lutra*)

Rabbit (*Oryctolagus cuniculus*)

Rat (*Rattus spp.*)

Stoat (*Mustela erminea*)

Water Vole (*Arvicola amphibius)*

Birds

Blackbird (*Turdus merula*)

Black-headed gulls (*Chroicocephalus ridibundus*)

Buzzard (*Buteo buteo*)

Carrion crow (*Corvus corone*)

Common sandpiper (*Actitis hypoleucos*)

Crossbill (*Loxia curvirostra*)

Curlew (*Numenius arquata*)

Dartford warbler (*Sylvia undata*)

Dipper (*Cinclus cinclus*)

Dunlin (*Calidris alpine*)

Fieldfare (*Turdus pilaris*)

Golden plover (*Pluvialis apricaria*)

Hobby (*Falco subbuteo*)

Kingfisher (*Alcedo atthis)*

Lapwing (*Vanellus vanellus*)

Magpie (*Pica pica*)

Marsh tit (*Poecile palustris*)

Meadow pipit (*Anthus pratensis*)

Merlin (*Falco colombarius*)

Nightjar (*Caprimulgus europaeus*)

Pheasant (*Phasianus colchicus*)

Pied flycatcher (*Ficedula hypoleuca*)

Redshank (*Tringa totanus*)

Red grouse (*Lagopus lagopus scotica*)

Redwing (*Turdus iliacus*)

Ring Ouzel (*Turdus torquatus*)

Short-eared owl (*Asio flammeus*)

Skylark (*Alauda arvensis*)

Snipe (*Gallinago gallinago*)

Sparrowhawk (*Accipiter nisus*)

Stonechat (*Saxicola rubicola*)

Swallow (*Hirundo rustica*)

Tree pipit (*Anthus trivialis*)

Twite (*Linaria flavirostris*)

Willow tit (*Poecile montanus*)

Wood warbler (*Phylloscopus sibilatrix*)

Fish

Stickleback (*Gasterosteidae* family)

Rainbow Trout (*Oncorynchus mykiss*)

European bullhead (*Cottus gobio*)

Invertebrates

Ash-grey slug (*Limax cinereoniger*)

Beetle (*Coleoptera*)

Bilberry bumblebee (*Bombus monticola*)

Brown argus (*Aricia agestis*)

Caddisfly (*Trichoptera*)

Common furniture beetles (*Anobium punctatum*)

Cranefly (*Tipulidae*)

Dark green fritillary (*Argynnis aglaja*)

Demon shrimp (*Dikerogammarus haemobaphes*)

Dingy skipper (*Erynnis tages*)

Earthworm (*Lumbricidae*)

Heather beetle (*Lochmaea suturalis*)

Forest cuckoo bee (*Bombus sylvestris*)

Jumping weevil (*Rhynchaenus testaceus*)

Killer shrimp (*Dikerogammarus villosus*)

Lemon slug (*Malacolimax tenellus*)

Mayfly (*Ephemoptera*)

Northern wood ant (*Formica lugubris*)

Purple hairstreak (*Favonius quercus*)

Sallow guest beetle (*Melanopion minimum*)

Signal crayfish (*Pacifastacus leniusculus*)

Silverfish (*Lepisma saccharina*)

Silver-washed fritillary (*Argynnis paphia*)

Stonefly (*Plecoptera*)

Swan mussel (*Anodonta cygnea*)

Two spotted oak buprestid (*Agrilus pannonicus*)

White-clawed crayfish (*Austropotamobius pallipes*)

White-letter hairstreak (*Satyrium w-album*)

White-spotted pinion moth (*Cosmia diffinis*)

Zebra mussel (*Dreissena polymorpha*)

Other

Ash dieback (*Hymenoscyphus fraxineus*)

Box blight fungus (*Cylindrocladium buxicola*)

Bulgy eye (*Cryptosporidium baileyi*)

Chytridiomycosis (*Batrachochytrium dendrobatidis; B. salamandrivorans*)

Crayfish plague (*Aphanomyces astaci*)

Date-coloured waxcap (*Hygrocybe spadicea*)

Liver fluke *(Fasciola hepatica)*

Louping Ill (Tick-borne Flavivirus)

Phytophthora (*Phytophthora spp.*)

Ranaviral disease (*Ranavirus spp.*)

Snake Fungal Disease (*Ophidiomyces ophiodiicola*)

Waxcap fungi (*Hygrocybe spp.*)

Aldern House, Baslow Road, Bakewell Derbyshire DE45 1AE

T: (01629) 816200 e: customer.service@peakdistrict.gov.uk

Your comments and views on this document are welcomed and can be directed to Holly Waterman, Senior Strategy Officer — Research, on 01629 816253 or at holly.waterman@peakdistrict.gov.uk

Member of National Parks UK (NPUK) and National Parks England (NPE). Holder of the Council of Europe Diploma.