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Assessing the potential consequences of climate change for England's landscapes: Sherwood

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Project details

This work was carried out in order to consider the vulnerability of the natural environment to climate change in Sherwood. It was undertaken by: Louisa Aspden, Nicholas Macgregor and Andy Neale from Natural England, and Nikki Van Dijk and Geoff Darch from Atkins.

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Summary

This study considered the vulnerability of the natural environment to climate change in the Sherwood area. This area encompasses the Sherwood heaths, which run north from Nottingham to Worksop; the Dukeries, an area of parkland and woodland south-west of Worksop; and the arable landscape of the sandstone estate in the northernmost part of the NCA. The Sherwood NCA lies over a major aquifer, supports nationally significant commercial agriculture, and contains internationally important wood pasture and parkland, large areas of lowland heath, and many buildings and landscape features of historic and cultural importance.

The vulnerability of the natural environment in the Sherwood NCA was assessed by considering how it is exposed to changes in climatic conditions, how sensitive it is to those changes (including its ability to adapt, which can be influenced by its current condition) and how much scope there is for conservation management to promote adaptation. This assessment of vulnerability is based on the best available scientific knowledge of how climate change might affect the natural environment and on discussions with local experts. The assessment considered both landscape assets (biodiversity, heritage, soils and geology) and its ecosystem service functions.

The report also suggests a range of possible adaptation actions to respond to these potential changes.

We carried out the vulnerability assessment at the level of assets which contribute to landscape character, biodiversity and ecosystem services. While the vulnerability of assets depends on a range of factors, we identified a number of changes in climate variables which are likely to affect the assets of Sherwood NCA. We found that changing rainfall patterns (wetter winters, drier summers, and more intense rainfall events) increased the vulnerability of most assets. Increased pest and disease risk resulting from warmer winters was also a common factor in many vulnerability assessments.

A consistent finding across the assessment was that a supply of fresh water and healthy soil are essential to reducing the vulnerability of assets to the impacts of climate change. These services will be affected by climate change, and in turn will affect the ability of other assets and services to adapt to climate change.

The projected change in rainfall patterns could have very significant direct and indirect impacts on all Sherwood's habitats. Drier summers may result in additional stress to veteran trees and result in changes in plant and invertebrate community composition. Sherwood's effective commercial agriculture is highly dependent on a water supply for irrigation. Moreover, should the aquifer fail to recharge as effectively, the provision of fresh water to a wide area of the Midlands could be affected.

The combination of wetter winters and drier summers will have significant adverse impacts on the soil. The soil is fundamental to the Sherwood landscape, shaping its historical use, the key habitats such as heathland and wood pasture, and supporting commercial agriculture, carrot and potato crops in particular. Increased erosion is a likely result of climate trends. Damage to the condition of the soil is likely to result in consequential damage to other key ecosystem services, most notably to the range of habitats, to agricultural productivity, to the quality of access to the environment, and to the buried historic environment. Historic environment assets seem to be particularly sensitive to climate change and have very limited adaptive capacity. As they are a non-renewable resource, reducing their vulnerability to climate change is important.

Shifts in the composition of plant communities in response to climate change appear to be a potential impact across habitats. The extent to which this matters, however, to landscape character and ecosystem services appears variable. Increased bracken encroachment on heathland and lowland acid grassland is a problem already and, unchecked, would fundamentally alter the habitats. In contrast, a change in species distribution in lowland mixed deciduous woodland is unlikely to affect the overall appearance of Sherwood as a wooded landscape, and non-specialist species are likely to

be able to adapt. The challenges facing specialist species are uncertain, but may perhaps be presumed to be more severe.

The report identifies that there are three areas of Sherwood NCA where valued assets may be particularly vulnerable as a result of climate change:

- Rivers, lakes, streams and their corridors.
- Areas of wood pasture, ancient woodland, veteran trees, and associated heathland and grassland habitats in the central area of Sherwood.
- The historic parks, country houses and associated buildings of the Dukeries.

This report also notes that elements of Sherwood's natural environment and the services it offers are relatively resilient to climate change, with greater adaptive capacity. Our assessment of vulnerability found that the ability of communities to enjoy access and recreation will be relatively unaffected, noting that a number of adaptation measures will increase its resilience. Similarly, the geological resource within the sandstone is well able to adapt, protecting the aquifer to some extent. Also reassuring is the conclusion that the caves and tunnels which are such a prominent historic asset of Nottingham should be resilient. Agriculture and timber production are also likely to have a high capacity to adapt to climate pressures, because they are a highly managed resource.

Part four of the report identifies specific adaptation options in relation to soils, water, woodland, heathland, the historic environment and access and recreation, as well as a number of strategic level actions.

It is hoped that the findings of this study of climate change vulnerabilities and potential adaptation options will provide a useful starting point for adaptation in the Sherwood NCA. The actions described in the study are designed to increase the adaptive capacity of the natural environment in the area to the impacts of climate change and ensure that society continues to enjoy the benefits the environment currently provides. While some of the impacts of climate change on the natural environment are uncertain, adaptation action taken now will improve the resilience of the natural environment to change whether this is from climate change or other pressures, and provide a range of other benefits.

Contents

Appendices

List of tables

List of figures

List of plates

1 Introduction

Context

1.1 England's natural environment is important for the species and ecosystems it supports and for the benefits it provides society. We enjoy a wide range of services from our environment, food and water, clean air, storage of carbon, regulation of hazards such as flooding, opportunities for recreation; and distinctive landscapes, shaped over thousands of years by natural processes and human land-use, that give both local communities and visitors a 'sense of place'. The natural environment contributes to our livelihoods as well as our health and well-being.

1.2 However, the natural environment is vulnerable to climate change (for example, Hopkins *et al*., 2007; Mitchell *et al*., 2007; IPCC 2007; Rosenzweig *et al*., 2007; Inter-Agency Climate Change Forum 2010). Landscapes are dynamic and have responded to changes in the past, but the scale and rate of projected change, coupled with existing pressures on the natural environment, is likely to have serious implications for the wide range of benefits and services we obtain from ecosystems and landscapes and the species that they support. At the same time, appropriate land management to preserve and enhance ecosystems can help buffer society from a changing climate (Morecroft & Cowan 2010). Adaptation action for the natural environment will therefore be essential and form an important part of our overall adaptation effort.

1.3 We have a general idea of how the climate might change (for example, Murphy *et al*., 2009), and some information about the possible consequences for different aspects of the natural environment (for example, Hopkins *et al*., 2007; Mitchell *et al*., 2007). However, consequences of climate change are likely to vary greatly from place to place. For the same reason, adaptation is likely to be a very time - and place - specific activity. Several sets of principles have been developed for adaptation (for example, Hopkins *et al*., 2007; Smithers *et al*., 2008; Macgregor & Cowan 2011), which have an important role in guiding general approaches. However, these need to be applied and tailored to specific locations and different landscape and habitat types, to help develop detailed adaptation solutions for different areas.

1.4 A key issue therefore is the scale at which adaptation action should take place – spatially, temporally and institutionally. Spatially, large scale approaches are likely to be important. This is not a new idea in conservation (for example, Noss, 1983), but climate change and its potential to further enhance the 'fluidity' (Manning *et al*., 2009) of landscapes in time and space makes it a particularly relevant issue to adaptation (for example, Opdam and Wascher, 2004). The recently published Lawton Review, Making Space for Nature, sets out a number of recommendations for practical action to achieve a coherent and resilient ecological network in England. The Lawton Review summarises the approach which needs to be adopted to support and enhance England's nature, as 'more, bigger, better and joined' (Lawton *et al*., 2010). Central to the delivery of this vision is a large scale approach to conservation and adaptation. It is also important that we try to take an integrated and sustainable approach to considering vulnerability and adaptation (for example, Macgregor and Cowan, 2011).

1.5 The concept of 'landscape' is particularly useful to address both scale and sustainability issues. As well as providing a spatial dimension, landscape has great potential to act as an integrating framework that can help us to consider a range of aspects of the natural environment in a holistic way, to consider how changes to physical features of the landscape will affect the things that society values and benefits from, and to focus our adaptation responses on maintaining or enhancing those things in the face of inevitable change.

1.6 National Character Areas (NCAs), which make up a well-established spatial framework across England (Figure 1) provide a suitable geographic unit to explore vulnerability and adaptation.

Ranging in size from 1,122 ha[1] to 382,627 ha, they provide an opportunity to consider vulnerability and adaptation at a 'landscape scale'; but are small and distinct enough (each having a well-described and distinctive set of geological, biological and cultural characteristics) to enable us to explore the possible implications of climate change in specific different places.

Natural England's Character Area Climate Change Project

1.7 The Character Area Climate Change Project commenced in 2007. It began with a set of four pilot studies that trialled a methodology that used bioclimatic data, information from national experts, and workshops with external stakeholders. It broadly followed a 'top-down' or hazard-based approach to impact assessment and adaptation (Parry and Carter, 1998; see also Jones and Mearns, 2005). The research reports from these early studies (Natural England 2009a,b,c,d), their summaries and an overall summary were published in 2009. The NCAs studied were:

- Cumbria High Fells in the Lake District area of north west England - a mountainous landscape with many lakes and peat soils.
- Shropshire Hills in the West Midlands, bordering Wales - a farmed landscape with fragmented heathland areas and diverse geology.
- Dorset Downs and Cranborne Chase in the south west of England - a rolling chalk landscape characterised by calcareous grassland and chalk stream valleys.
- The Broads on the east coast of England - a low lying freshwater wetland landscape with large areas of open water.

1.8 A second phase of studies commenced in 2009. The second phase built on the lessons learnt in the pilot studies and a revised methodology was developed, focusing on assessing vulnerability to climate change and increasing resilience of the natural environment. This drew on 'bottom-up' methodologies associated with vulnerability assessment (see for example Kelly and Adger, 2000; Downing and Patwardhan, 2005) and the concept of resilience (see for example Handmer and Dovers, 1996). The NCAs in the second phase of studies were:

- Sherwood in the East Midlands, bordering on the Yorkshire and Humber region – rolling countryside, with well established, iconic woodlands and a strong coal mining heritage.
- South East Northumberland Coastal Plain on the north east coast of England – a flat landscape with coastline of sand dunes and rocky outcrops, scarred by a heavily industrial past.
- Humberhead Levels, inland of the Humber estuary – a broad floodplain of navigable rivers, and an important area of lowland peat.
- London[2] – a large city, but with extensive urban green space, dominated by the influence of the river Thames.
- South Downs National Park[3], stretching from Eastbourne to Winchester in the south east of England – a chalk landscape of rolling arable fields and close-cropped grassland on the bold scarps, with rounded open ridges.

[1] Excluding the two smallest NCAs, Lundy and the Isles of Scilly

[2] Rather than a single NCA, the study looked at the whole Greater London administrative area, which overlaps a number of NCAs

[3] This study extended beyond the South Downs NCA to include parts of other NCAs that lie within the National Park boundary

- Lancashire and Amoundness Plain on the Irish Sea coast in the north west of England – a flat, predominantly drained coastal marsh landscape of mostly peat soils which has seen significant coastal development of Victorian coastal resorts.
- Morecambe Bay Limestones to the north of Lancashire and Amounderness Plain – a contrasting landscape of limestone hills interspersed with flat agriculturally-reclaimed flood plains, surrounding the multiple estuaries and mudflats that make Morecambe Bay.
- Solway Basin in the far north west of England, bordering Scotland – a broad lowland coastal plain gently rising to the hills behind with large expanses of intertidal mudflats backed by salt marsh.

1.9 The 12 studies completed in the two phases of the project cover a wide range of landscape types across England (Figure 1).

Figure 1 England's 159 National Character Areas, with the 12 areas studied in the two phases of the project highlighted. Sherwood is shaded in yellow

1.10 This report presents the results of the Sherwood study. Chapter 2 outlines the overall approach taken in this study and the other studies in the second phase of the project while Chapter 3 describes the specific methods used in the Sherwood study. The results of the study are presented in Chapter 4 and briefly discussed in Chapter 5.

2 Approach

Introduction

2.1 This study and the others in the second phase of the Natural England Character Area Climate Change project are underpinned by three main concepts:

- sustainable adaptation;
- using a vulnerability approach to assess the potential effects of climate change; and
- using landscape as an integrating framework for adaptation.

2.2 This chapter defines these concepts and describes how they have been used to inform the methodology used.

Sustainable adaptation

2.3 Adaptation must be sustainable. Four principles for sustainable adaptation have been proposed (Macgregor and Cowen 2011):

1) Adaptation should aim to maintain or enhance the environmental, social and economic benefits provided by a system, while accepting and accommodating inevitable changes to it.
2) Adaptation should not solve one problem while creating or worsening others. We should prioritise action that has multiple benefits and avoid creating negative effects for other people, places and sectors.
3) Adaptation should seek to increase resilience to a wide range of future risks and address all aspects of vulnerability, rather than focusing solely on specific projected climate impacts.
4) Approaches to adaptation must be flexible and not limit future action.

2.4 An important aspect of applying the first principle above is to consider, as a starting point, the benefits a system provides, in order to establish objectives for adaptation against which both the consequences of climate change and the sustainability of possible adaptation actions can be evaluated. This thus frames the question from the point of view of 'what are we adapting for?' rather than 'what impacts are we adapting to?'

2.5 An important aspect of sustainable adaptation is to identify action that would maintain or enhance the multiple benefits an area provides to society by reducing vulnerability to a range of possible consequences of climate change (principle 3 above). Therefore, in this project we have not chosen a specific climate change scenario (for example, 2080s, high emissions) to assess the vulnerability of the natural environment or identify adaptation responses. The project aimed to develop adaptation responses which are valid for a broad range of climate changes, using the headline messages from the United Kingdom Climate Projections 2009 (UKCP09) (see Vulnerability assessment, below). In the face of uncertainty about the magnitude and timing of climatic changes and the cascade of possible consequences for natural systems, we believe this approach is more appropriate than focusing solely on trying to identify and respond to detailed projections of climate impacts. This is one of the key lessons that emerged from the phase one studies (Natural England 2009a, b, c, d).

Vulnerability assessment

2.6 Following the sustainable adaptation framework, a bottom-up, vulnerability based approach to assessing the potential impacts of climate change on the natural environment of the NCAs was taken. Vulnerability has been defined by the Intergovernmental Panel on Climate Change (IPCC) as a function of a system's exposure and sensitivity to climate impacts and its capacity to adapt (IPCC 2007; Figure 2), where:

- sensitivity refers to the degree to which a system is affected by weather or climate related stimuli (Willows and Connell 2003);
- exposure refers to the extent to which the system is subject to the weather or climate variable in question; and
- capacity to adapt refers to the ability of a system to adjust to climate change, to moderate potential damage or to take advantage of opportunities (Willows and Connell 2003).

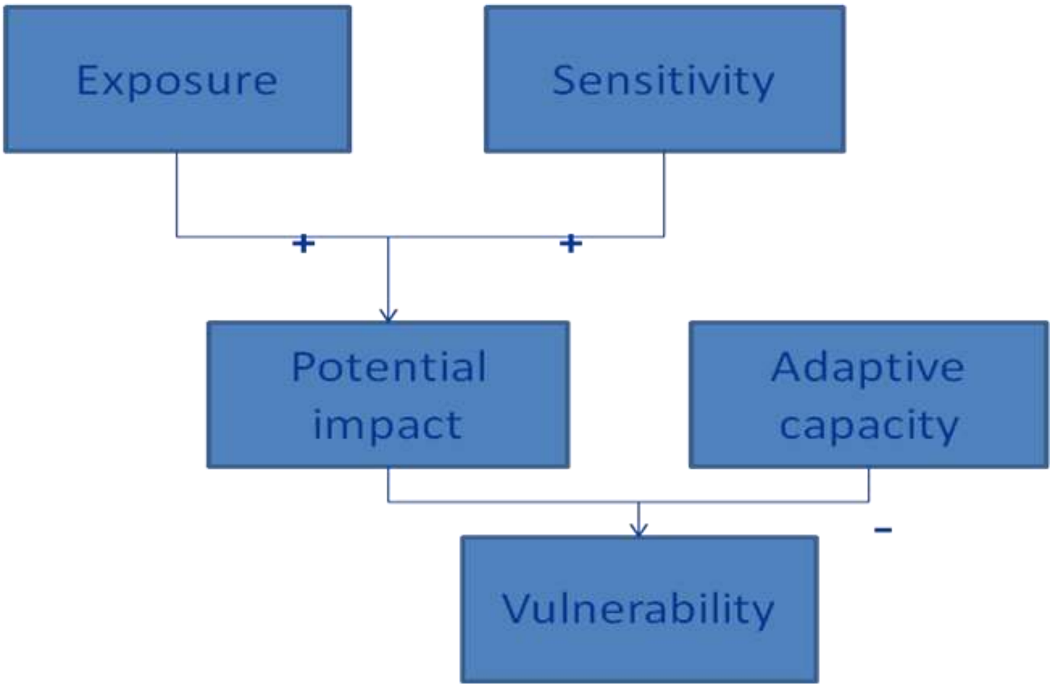

Figure 2 The basic components of vulnerability

2.7 The IPCC vulnerability framework distinguishes between 'natural' and 'human-managed' adaptive capacity (IPCC 2007), and further studies (for example, Williams *et al.,* 2008, Steffen *et al*., 2009, Glick *et al*., 2011) have explored in more detail the factors that influence vulnerability in complex natural systems.

2.8 Exposure is determined by two factors. The first of these is the general change in climate variables that occurs in the area of interest. Information on change in climate variables can be found in the United Kingdom Climate Projections 2009 (UKCP09) (Murphy *et al*., 2009). The UKCP09 projections provide probabilistic projections of climate change, assimilated from an ensemble of models and model runs for three emissions scenarios (Low, Medium and High). The projections are presented for 25 x 25 km grid squares across the UK and for seven over-lapping 30-year 'timeslices' (30 year averages of climate variables), moving forward in decadal steps (2010-2039, 2020-2049, until 2070-2099).

2.9 Headline messages for the UK from UKCP09 can be summarised as:

- All areas of the UK get warmer and the warming is greater in summer than in winter.
- There is little change in the amount of precipitation that falls annually but it is likely that more of it will fall in winter with drier summers for much of the UK.
- Sea levels rise and are greater in the south of the UK than the north.

2.10 Second, the exposure of a particular feature (for example, a plant or an animal, or an archaeological feature) may be moderated by the physical structure of the environment in the immediate vicinity. For example, even though an overall area might experience a certain average temperature rise, sites that are naturally cool and shaded (for example, sheltered wooded valleys) are likely to reach a lower maximum temperature than nearby sites in direct sun, such as open hilltops.

2.11 Sensitivity to a climatic change is determined by intrinsic traits of a feature, such as a species' tolerance to changes in temperature or water availability or the type of material used to build a historic property and the extent to which it is affected by flooding. Sensitivity in a particular location is also likely to be exacerbated by the presence of *non-climate pressures*. For example, areas of blanket bog that are already water-stressed as a result of existing drainage are likely to be more sensitive to additional water shortage in drier summers than are areas in good condition with sufficient water resources. Historic features in a poor state of repair might be more sensitive to damage from heavy rainfall than features that have been well conserved.

2.12 Capacity to adapt is determined by three sets of factors:

- For living things, it is the intrinsic traits of a species that enable it to adjust to changing conditions. This includes the capacity for phenotypic plasticity[4], such as adjustment of an animal's behaviour to use different microhabitats or to be active at different times of the day the ability of an animal, or the seeds of a plant, to disperse to other, more suitable areas; changes in phenology, that is timing of seasonal events such as egg hatching, migration and leafing; and capacity to adapt (in an evolutionary sense) *in situ* to be more adapted to the new conditions, which will be constrained by the existing level of genetic diversity in a population and the species' generation time.
- The local environment, which can either support or hamper a species' intrinsic ability to adapt. For example, a species might have the ability to modify its behaviour to use different microhabitat in its current range, or to disperse to new habitat in a different area, but will be able to successfully adapt only if suitable habitat is available and accessible.
- For both living and non-living features, the ability of humans to manage the system ('adaptive management capacity'; Williams *et al*., 2008). Factors such as the existence of management plans or policies which consider climate change, measurement and monitoring of the impacts of climate change, availability of land for people to allow translocation or migration of wildlife or to move non-living features, and the existence of partnerships to manage features, can all contribute to adaptive management capacity.

Dealing with uncertainty in vulnerability assessment

2.13 There are multiple sources of uncertainty in the vulnerability assessment that make it difficult to make an objective assessment of the vulnerability of features of the natural environment to the impacts of climate change. There are a range of projections of climate change due to natural climate variability, incomplete understanding of Earth system processes and a range of possible scenarios of future greenhouse gas emissions (Jenkins *et al*., 2009). Another source of uncertainty is added when translating the projections into potential impacts on the natural environment: our understanding of how the complex interactions which exist in the natural environment will respond to climate change is limited.

2.14 While acknowledging these various sources of uncertainty, we understand enough about possible climate change and its potential effects on the natural environment to consider a range of plausible future changes. The aim of the vulnerability assessment in these studies

[4] Phenotypic plasticity is the ability of an organism to change its morphology, development, biochemical or physiological properties, or behaviour, in response to changes in the environment

was to highlight the relative vulnerability of features in the NCA to the impacts of climate change, based on the best knowledge available at present. Sources of information included expert judgement of Natural England specialists, other experts from outside the organisation, including local experts, and published literature. By setting out each feature in terms of its exposure and sensitivity to climate change and its capacity to adapt, the justification for the assessment was made as transparent as possible.

Landscape as an integrating concept

2.15 The third central concept is the idea of landscape as an integrating framework for adaptation (and for conservation in general). Landscape in this sense is far more than just ‘the view’ – it is the full set of environmental features in an area and the services they provide. In these studies, landscape was considered in terms of a range of physical features that combine and interact to produce important services and benefits. Three broad categories of benefits were considered: biodiversity, landscape character and other ecosystem services.

2.16 Landscape character refers to the distinct, recognisable and consistent pattern of elements that make one landscape different from another and provide people who live there or visit with a ‘sense of place’. The concept of landscape character does not imply any value judgement ie it does not make a distinction between landscapes that are better or worse, but considers the distinct, recognisable and consistent pattern of elements that make one landscape different from another. This might include physical features such as hedgerows or buildings but also physical patterns at different spatial scales. These elements come together to influence how people perceive landscapes. National Character Areas are discreet areas that, in broad terms, have a coherent landscape character that differs from that of neighbouring areas. The benefits to people provided by valued landscape character are just some of a wider range of ecosystem services (see below) that landscapes provide, but because landscape character determines how a place ‘looks and feels’ to people (which was an important aspect of these studies), it was considered in a separate category here.

2.17 Ecosystem services are the wide range of services the natural environment delivers to society (Daily 1997). They can be described as “the processes or structures within ecosystems that give rise to a range of goods and services from which humans derive benefit” (Parliamentary Office of Science and Technology 2007).

2.18 The Millennium Ecosystem Assessment (MA 2005) identified four types of ecosystem services:

- Provisioning services such as food and forestry, energy and fresh water.
- Regulating services such as climate regulation and water purification.
- Supporting services such as soil formation and pollination.
- Cultural services such as recreation, inspiration and sense of place.

2.19 Biodiversity (short for biological diversity) is the variety of all life forms: the different plants, animals and micro-organisms, their genes, and the communities and ecosystems of which they are part. Biodiversity is usually recognised at three levels: genetic diversity, species diversity and ecosystem diversity. As well as being valuable in its own right, it supports ecosystem services and contributes to the character of a landscape.

2.20 Landscape character, ecosystem services and biodiversity are the result of a combination of elements such as habitats, geology, soil types and land use and the interactions between them. A very simple example of this might be trees and hedgerows which combine to give a landscape a wooded character, provide habitats for wildlife and also deliver services such as carbon sequestration or soil conservation. Features such as this that make an important contribution to character, ecosystem services or biodiversity are referred to as ‘assets’ in this study.

2.21 This study, and the others in the second phase of the Character Area Climate Change project, brought together these three concepts (sustainable adaptation, vulnerability assessment, landscape as an integrating framework) to develop and test a method for an integrated landscape and ecosystem approach to adaptation.

3 Method

3.1 The method we followed in this study (and in the parallel studies noted above) for assessing vulnerability and considering adaptation options consisted of six steps (Figure 3). The starting point was to identify the most important aspects of landscape character, ecosystem services and biodiversity, and the physical assets which make the most important contribution to them. We then assessed the vulnerability of those physical assets, and from this we inferred what major changes to character, biodiversity and ecosystem services might potentially occur as a result.

3.2 We also identified possible adaptation actions to address vulnerability and screened them to identify actions that would have multiple benefits, and any potential conflicts between actions. The remainder of this chapter outlines in more detail how we undertook each of the steps.

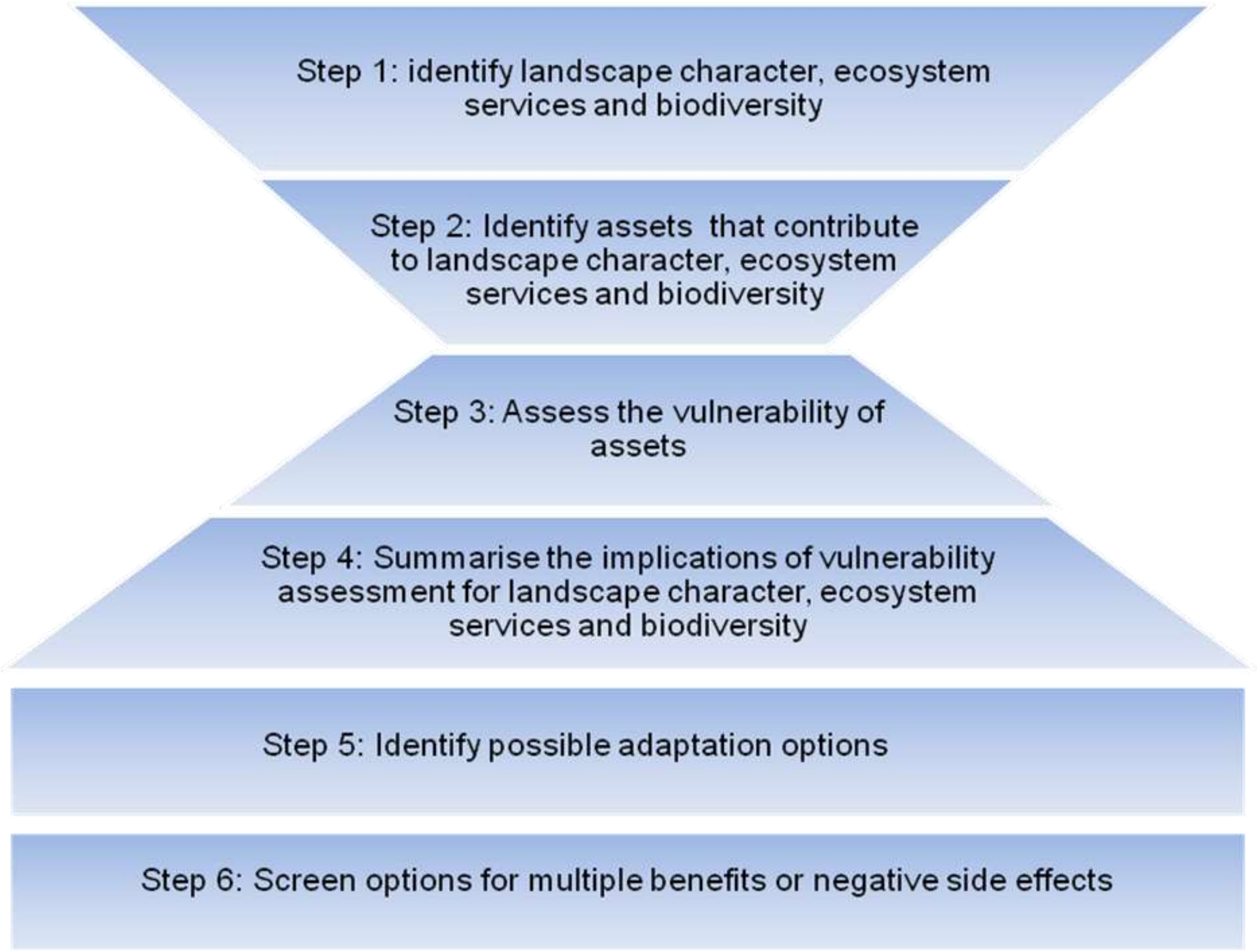

Figure 3 The main steps in the method used to assess vulnerability of the area to climate change and to identify and evaluate possible adaptation options

Step 1 – Identify important elements of landscape character, ecosystem services and biodiversity

3.3 The most important elements of landscape character, ecosystem services and biodiversity of Sherwood were identified through a review of the current NCA description (Countryside Commission 1999) and consultation with regional landscape specialists currently working to re-define the NCA profile and objectives.

3.4 Consideration was given to identifying the urban character of the NCA. Twenty-six percent of Sherwood is urban, including much of the city of Nottingham, the large town of Mansfield, and the market towns of Worksop and Kirkby in Ashfield. We did not have access to townscape character assessments, and the NCA landscape assessment of Sherwood refers to urban influences but does not fully capture the urban elements. In order to overcome this, we sought views on the urban character of the NCA from external stakeholders with good local knowledge of the urban areas of Sherwood.

Step 2 – Identify assets which contribute to landscape character, ecosystem services and biodiversity

3.5 We identified the assets which contribute to the landscape character, ecosystem services and biodiversity of Sherwood under the following headings:

- Geology and soils.
- Habitats and species.
- Areas for access and recreation.
- Historic environment.
- Natural resources.
- Other key elements of landscape character not covered by the categories above.

3.6 The assets were identified by reviewing the NCA description and consulting Natural England specialists and local experts. In particular, habitats were identified in consultation with the Sherwood Habitats Strategy Group, which comprises the main land owning and management bodies in the area. In addition, many of the assets were mapped using spatial data held by Natural England. The maps presented in this report illustrate information that Natural England holds on certain asset types and do not necessarily include every asset. There are also some types of assets which do not lend themselves to mapping (for example, aspects of aesthetic value and sense of place).

3.7 The validity of the output of Steps 1 and 2 was checked through correspondence with Natural England staff. Further checking was undertaken at a workshop for local experts held in January 2010.

Step 3 – Assess how the assets may be vulnerable to the impacts of climate change

3.8 The relative vulnerability of each asset to the effects of climate change was assessed, considering exposure, sensitivity and adaptive capacity. Vulnerability to both direct and indirect effects of climate change was assessed. The assessment was informed by national experts in Natural England and the local knowledge of regional specialists, as well as published and unpublished literature. At this point, the assessment described the nature of the vulnerability but did not classify the level of vulnerability of assets.

3.9 In determining the vulnerability of assets, we considered the following sources of information:

1) **Exposure**

Regional summaries from the UKCP09 climate projections under the medium emissions scenarios for the East Midlands were used to consider exposure (see example below), and to help identify the broad trends and associated impacts considered in this study (Table 1).

Headline messages for the East Midlands from the UKCP09 projections (for the 2080s, Medium emissions)

- The central estimate of increase in **winter mean temperature** is 3ºC; it is very unlikely to be less than 1.6ºC and is very unlikely to be more than 4.6ºC.
- The central estimate of increase in **summer mean temperature** is 3.5ºC; it is very unlikely to be less than 1.8ºC and is very unlikely to be more than 5.8ºC.
- The central estimate of increase in **summer mean daily maximum temperature** is 4.7ºC; it is very unlikely to be less than 2ºC and is very unlikely to be more than 8.3ºC.
- The central estimate of increase in **summer mean daily minimum temperature** is 3.8ºC; it is very unlikely to be less than 1.9ºC and is very unlikely to be more than 6.5ºC.
- The central estimate of change in **annual mean precipitation** is 1%; it is very unlikely to be less than –5% and is very unlikely to be more than 7%.
- The central estimate of change in **winter mean precipitation** is 19%; it is very unlikely to be less than 3% and is very unlikely to be more than 41%.
- The central estimate of change in **summer mean precipitation** is –20%; it is very unlikely to be less than –43% and is very unlikely to be more than 6%.

Table 1 Broad trends in climate variables and associated impacts considered in this study

Trends	Associated impacts
Hotter summers	Drought
Drier summers	Longer growing season
Warmer winters	Higher temperature
Wetter winters	Increased soil moisture deficit
More frequent storm events	Flooding
	Water logging of soils
	Erosion
	High winds

2) **Sensitivity**

Sensitivity was determined by considering the characteristics of the asset including its tolerance of a gradual directional change in climate, reaction to the impacts of one off ‘shock’ events, and the impact of a combination of two or more of these factors.

3) **Adaptive capacity**

To determine the adaptive capacity of environmental assets in the face of a changing climate, we considered whether the asset could adapt and retain its value by moving, through changes in habitat composition, or through natural or managed processes.

3.10 We summarised the results of our initial vulnerability assessment in a series of templates (one for each of the categories of assets listed above). The templates were circulated for consultation in autumn 2009 and we presented revised versions to knowledgeable local experts at a workshop held in January 2010.

3.11 At the workshop, participants rated the relative vulnerability of each asset using a scale of 'more vulnerable', 'moderately vulnerable' or 'less vulnerable' (Table 2). The process used to rate the assets was subjective and based on a qualitative assessment of the relative sensitivity of an asset to the impacts of climate change, its exposure to climate change impacts and its adaptive capacity. By splitting vulnerability into its components, and seeking the views of a range of stakeholders, we attempted to make the process as rigorous and transparent as possible, despite a lack of data on the definitive impacts of climate change on the natural environment and the necessarily subjective method of assessment.

Table 2 Vulnerability ratings used

Vulnerability rating	Definition
Less vulnerable	Asset is less likely to be significantly changed as a result of climate change, or change may be beneficial. Adaptation action may be necessary, but other assets should be considered with greater urgency.
Moderately vulnerable	Asset may be changed as a result of climate change. Careful management or monitoring is likely to be required to support adaptation.
More vulnerable	Asset is likely to be significantly changed or destroyed as a result of climate change. Adaptation action should be implemented as a matter of priority.

3.12 Following the workshop, we reviewed the results to ensure that we had sufficient justification for the vulnerability ratings and to identify and carry out any further necessary investigation.

3.13 The results of the vulnerability assessment are summarised in Chapter 4 and are presented in tables in Appendix 2.

Step 4 – Identify the potential major changes to landscape character, ecosystem services and biodiversity

3.14 Having identified the assets which make the most important contribution to landscape character, ecosystem services and biodiversity in Sherwood and assessed the vulnerability of those assets to climate change, we summarised the potential implications of climate change for the character, ecosystem services and biodiversity of Sherwood. We considered the cumulative effects of the vulnerabilities identified in Step 3 and from this developed a series of statements about potential major implications for the area, based on our local knowledge and consultation with Natural England regional landscape specialists.

Step 5 – Identify possible adaptation actions

3.15 Potential adaptation actions to address the vulnerability of the assets of Sherwood were identified using a combination of published literature (for example, Hopkins *et al*., 2007, Mitchell *et al*., 2007), expert opinion from Natural England specialist staff, and consultation with a wide range of local experts. When identifying potential adaptation actions, we considered the concept of adaptive management (Holling, 1978).

3.16 The lists of possible actions were shared with stakeholders during consultation and at the workshop in January 2010, and we refined them based on the comments received. Additionally, we asked workshop participants to identify up to three priority actions for the assets they were considering.

Step 6 – Screen options for multiple benefits or negative side effects

3.17 It was important that the adaptation actions identified in Step 5 did not have unintended negative impacts on the natural environment and that potential synergies between actions are recognised. To address this, all the potential adaptation actions identified in Step 5 were screened using a matrix, and by applying a number of principles to decide which adaptation actions were most appropriate:

- Win-win adaptation response – A "win-win" adaptation response is a response to climate change that reduces the vulnerability to climate change of more than one characteristic or service of the natural environment, providing multiple benefits (UKCIP n.d).
- Low regrets adaptation response – Adaptation measure that would be relatively cheap to implement and for which benefits, although primarily realised under projected future climate change, may be relatively large (UKCIP n.d).
- No regrets adaptation response – A response to projected climate change impact that is beneficial regardless of whether climate change occurs (UKCIP n.d).
- Avoiding conflict between adaptation responses – It will be important that when implementing one adaption response, the ability to carry out other adaptation responses should not be unduly compromised. This is a central tenet of the concept of sustainable adaptation, alongside the principle that adaptation responses should not increase climate change unnecessarily (Macgregor & Cowan 2011).

3.18 Screening exercises were carried out three times during the project:

1) An initial screening stage in November 2009.
2) As an exercise during the consultation event in January 2010.
3) In subsequent analysis of consultation responses and other responses collated during the write-up stage.

3.19 Some adaptation actions were discarded at this stage as inappropriate. A typical reason was that the response did not apply specifically to assets in the Sherwood character area.

3.20 Once the highest priority actions had been identified for specific assets in Sherwood, we grouped them under the statements of major potential changes identified in Step 5. In addition, we identified a number of potential more general adaptation actions that would help to provide a strategic framework for adaptation across the whole area. The actions are listed in Chapter 5, and the final matrix is reproduced as Appendix 4.

4 Results

Part 1 – Description of the area

4.1 In this part of the Results chapter, the findings of Steps 1 and 2 of the method are presented. We have identified the main features of the NCA under the headings of landscape character, ecosystem services and biodiversity. We have then identified the main assets which contribute to these features.

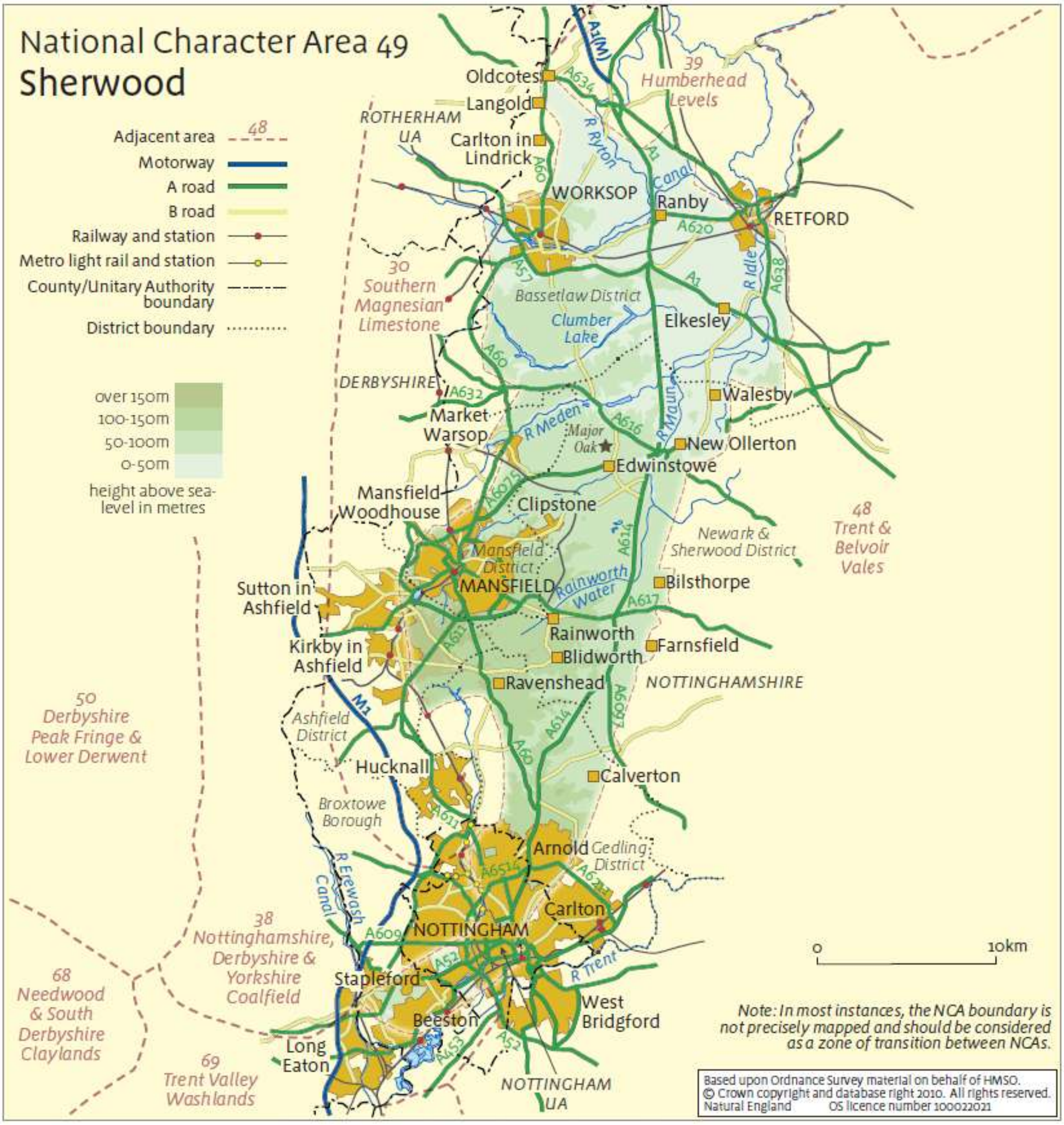

Figure 4 Map of Sherwood NCA

Landscape character

4.2 The Sherwood NCA stretches from Beeston, south west of Nottingham, through the centre of the city and northwards, to farmland north of Worksop and Retford abutting the Humberhead Levels NCA. To the west it adjoins the Magnesian Limestone NCA, and to the south and east, the Trent and Belvoir Vales and the Nottinghamshire Claylands. It includes much of the centre of Nottingham and its northern and western suburbs, and also encompasses the urban areas of Mansfield, Worksop and Retford, as seen in Figure 4. The NCA largely overlies sandstone, and the resulting well-drained, infertile sandy soils have greatly influenced the character of the area. Changes in the landscape across the area allow us to split it broadly into three sections (The Countryside Agency, 1999):

- Sherwood heaths run from the northern edge of Nottingham up to Worksop. This rolling landform gives an impression of a patchwork of large and small woodlands interspersed with farmland, and large fields with treeless hedges. It includes the remnant heart of Sherwood Forest, areas of extensive heathland, and prominent signs of past and present mining.
- The Dukeries lie south-west of Worksop. The area takes its name from the number of ducal country seats to be found there at one time, and has been heavily shaped by its management, from the eighteenth century, as large parks and estates. These parklands, along with extensive broad-leaved and coniferous woodlands, are the main features of a sparsely populated area.
- Sandstone estate lands form the northernmost part of Sherwood. This is an intensively farmed, sparsely populated, mainly arable landscape, with fewer trees and smaller estates and parks.

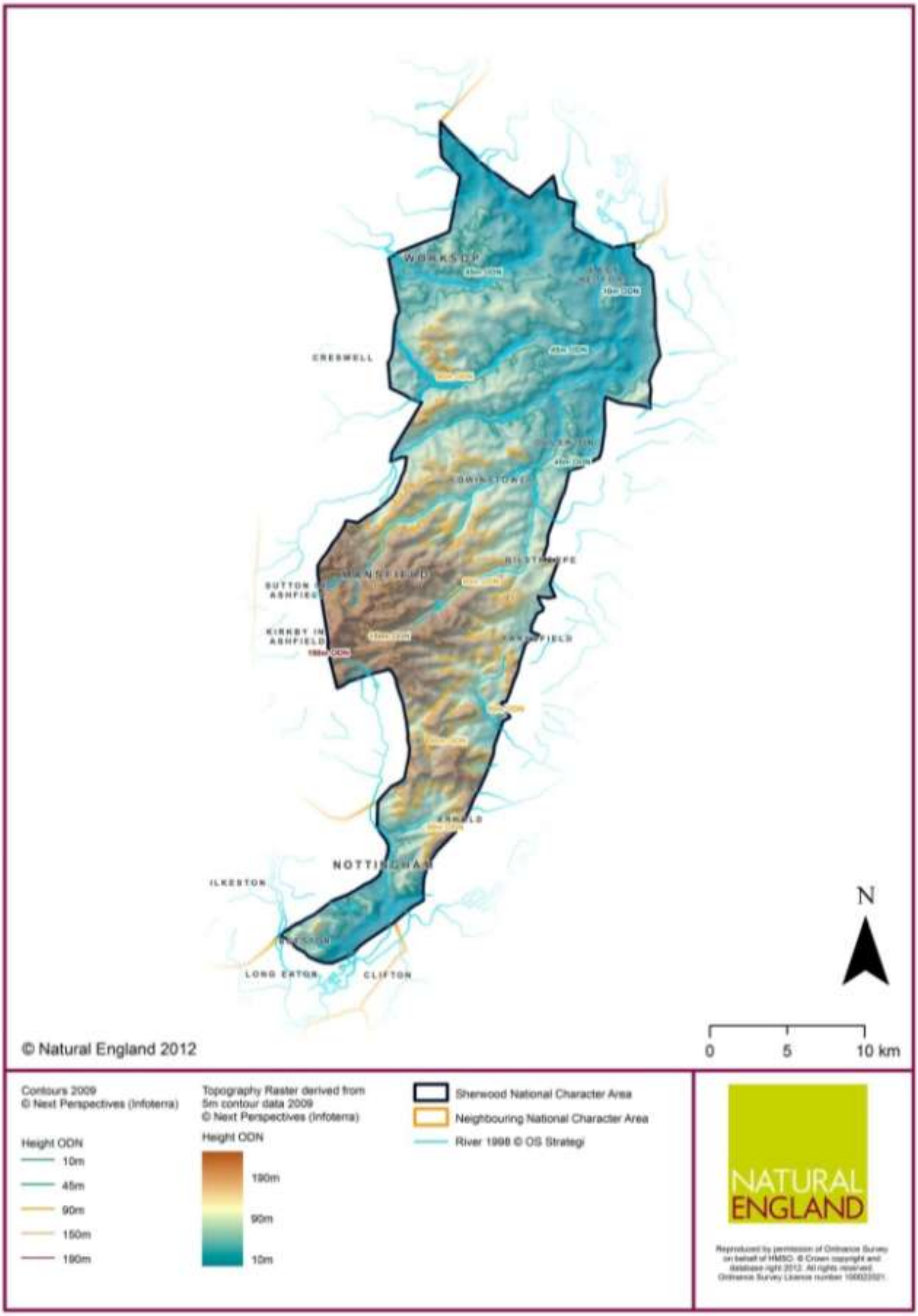

Figure 5 Topography of Sherwood NCA

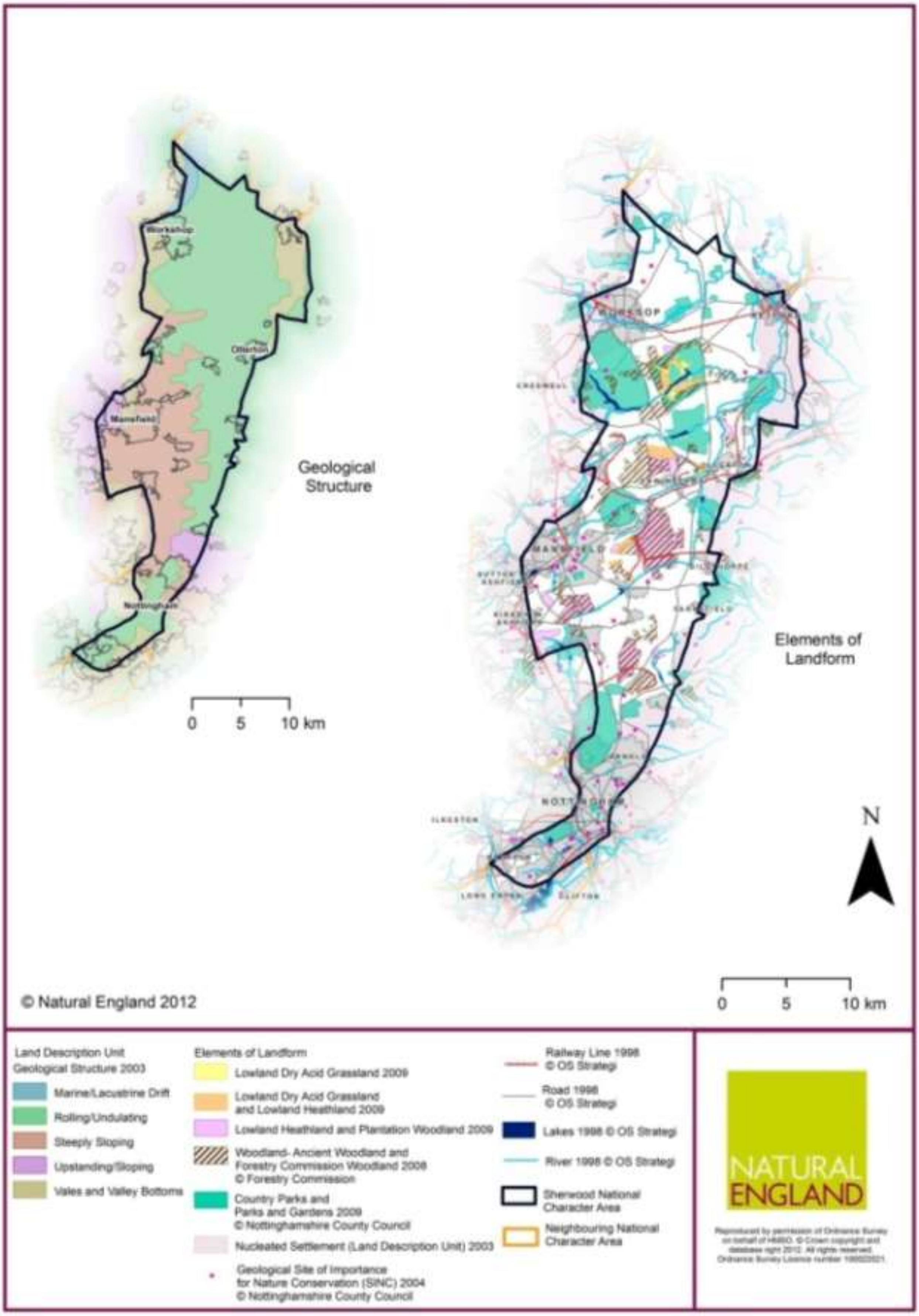

Figure 6 Elements of landscape form within Sherwood NCA

4.3 The main landscape characteristics of the NCA and the assets which contribute to them are as follows:

4.4 **Rolling landform overlying sandstone, with sandy soils and outcrops, dry valleys and long views:** Sherwood sandstones and conglomerates underlie most of the character area and shape the landform, with its medium and long views, frequent dry valleys, and characteristic bluffs and outcrops. The sandstone produces the orange-hued sandy soils which add vivid colour to the landscape, especially when farmland is relatively bare after ploughing. Refer to Figures 5 and 6.

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Plate 1 View from near Clipstone showing the heavily wooded character of Sherwood. The foreground is reclaimed acid grassland (former colliery site); Sherwood Forest Golf Club SSSI is in the middle distance and the forestry at Sherwood Pines lies beyond. Note the wooded skyline

4.5 **Large amount of woodland, with frequent views of wooded skylines:** Twenty percent of the NCA is wooded (Forestry Commission, 2006) and the over-riding impression of rural Sherwood is of a well-wooded character. The woodlands vary in scale and composition. Dense broad-leaved woodland and conifer plantation can be found in the Dukeries. Semi-ancient wood pasture forms the heart of the Sherwood National Nature Reserve (NNR) and Birklands and Bilhaugh Special Area of Conservation (SAC). Oak-birch woodland is common in the Dukeries, while conifer plantations in Sherwood Pines, near Edwinstowe, and elsewhere in the NCA, provide a strong contrast to mixed woodland elsewhere. Shelter belts and lines of poplars are locally conspicuous. Often, views, even long-distance ones, are bounded by woodland on all sides, giving a sense of enclosure and tranquillity.

4.6 **Locally conspicuous sandstone quarries:** Active quarries remain near Mansfield and Bestwood, and near Worksop in the north of the county. Most others are now closed and being restored.

4.7 **Extensive enclosed arable farmlands with rectilinear field patterns divided by low, treeless hedges:** The Sherwood NCA is farmed intensively. Post-enclosure field patterns remain the framework of the agricultural landscape in the area between the northern boundary of Nottingham and the edge of the Dukeries, and north of Worksop.

Plate 2 A view of Sherwood looking towards Blidworth, showing the undulating countryside, woodland, sandy soil and rectilinear arable fields typical of the landscape

4.8 **Strong heathland character:** The heathland character is particularly strong in the south and centre of the NCA. Large areas of internationally important lowland heath are found around Budby and Sherwood and at the edge of Mansfield. Gorse, broom and bracken, species indicative of remnant heath, are also found in road verges and woodland edges.

4.9 **Country houses set in ornamental parkland and architect-designed estate villages:** There are country houses and parklands throughout the area. There are nineteen registered parks and gardens in the NCA (English Heritage, 2011). Country houses with small parks, such as Babworth Park, are found in the north. Near Worksop are the notable houses and parks of the Dukeries at Clumber Park, Thoresby Hall, Worksop Manor and Welbeck Abbey. Further south can be found further examples of country houses and associated gardens and parks, including Lord Byron’s family home at Newstead Abbey, Rufford Park, and Wollaton Park in urban Nottingham. Perlethorpe is one of many architect designed estate villages in the Dukeries.

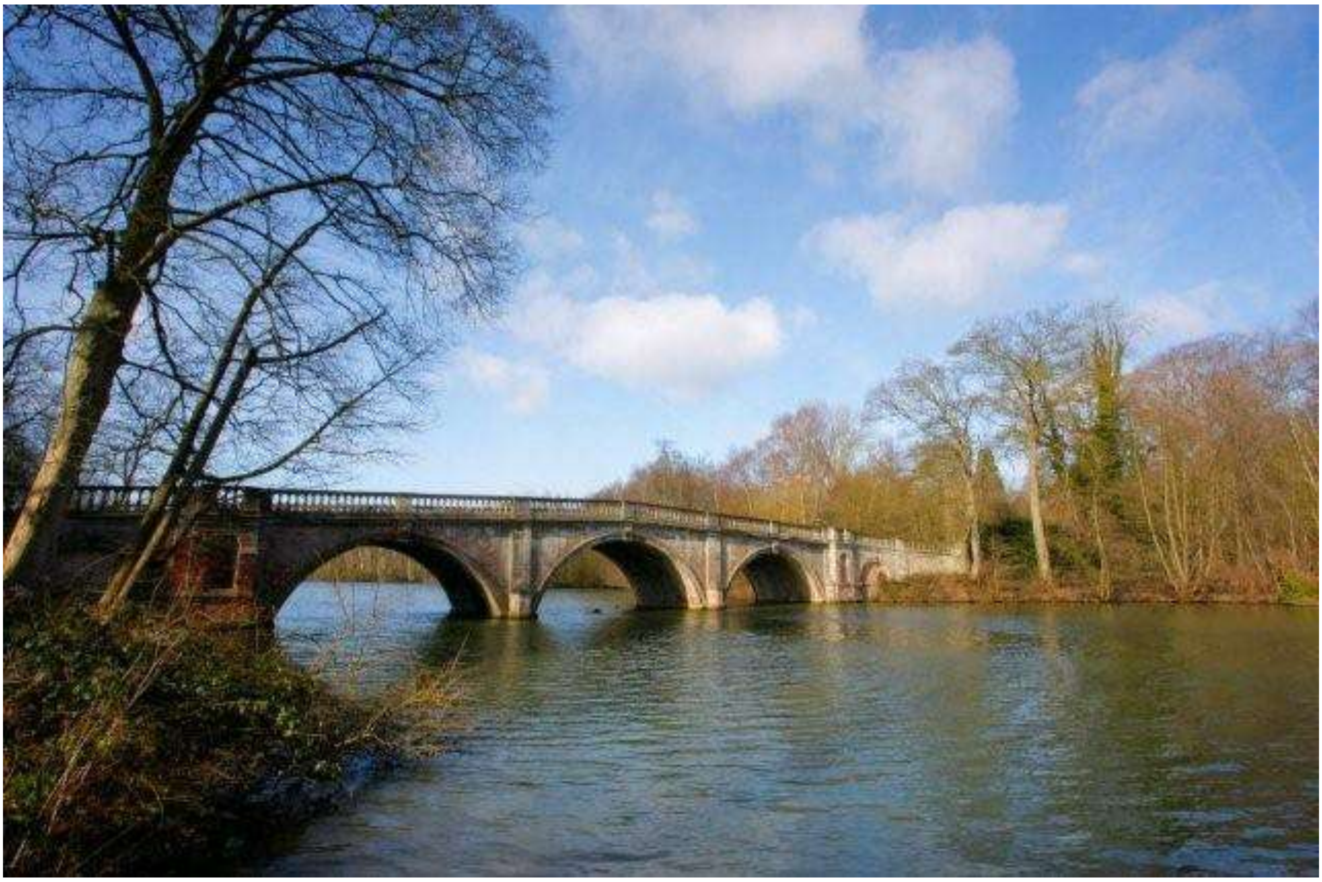

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Plate 3 Clumber Park Lake SSSI, and bridge

4.10 **Narrow man-made lakes, meandering river channels, flood meadows and, in places, fringing alder, willow and scrub:** The Rivers Maun and Meden flow east from the Mansfield area to form the River Idle at their confluence south of Retford. The Idle then continues north along the eastern side of the character area to join, eventually, the River Trent. The Poulter is another tributary of the Idle. The man-made ornamental lakes of Welbeck and Clumber Park lie along the River Poulter as it runs from west to east across the character area. Further north, the River Ryton flows into the character area at Worksop and then north to join the Idle, on the border with South Yorkshire. The River Leen drains the southern part of the area, flowing south into the Trent in Nottingham. None of these are large rivers, and low flows are a problem in summer. The Chesterfield Canal runs across the north of the NCA.

4.11 There are historic remains of water management systems, including water meadows, in Sherwood NCA but by and large these no longer function due to falling groundwater levels. The Duke of Portland’s flood meadow system along the Poulter is a famous example which operated until after the Second World War.

© Whitfield Benson/Natural England

Plate 4 Chesterfield Canal cuts through a sparsely settled rural landscape near Worksop, in the north of the NCA

4.12 **Mining heritage:** Evidence of medieval mining survives in places in the form of characteristic "bell pit" earthworks. Deep coal mining in the NCA began in the late nineteenth century, declining towards the end of the twentieth century. Former mining settlements, mining-associated remains, disused railways, and prominent areas of reclaimed former mining land are visible across the NCA, but mainly in the southern and central area, below Edwinstowe. In the limited area where mining continues around Edwinstowe, the headstocks and associated spoil heaps are conspicuous. Restored former mining land has been used for woodland and heathland re-creation. At the site of the former Ollerton colliery a low energy business and housing development has been created, with careful landscaping of the surrounding area.

4.13 **Vernacular buildings of handmade red brick and of sandstone:** Traditional buildings of narrow red hand-made bricks or local sandstone can be found as farm buildings or in village centres. Particularly good examples of agricultural buildings are found at Jordan's Castle Farm, Wellow.

4.14 **Locally distinctive rural settlement patterns:** The north of the NCA above Worksop is a sparsely settled landscape with scattered farmhouses and estate cottages. Further south, there is a nucleated settlement pattern of small red brick villages with some sandstone buildings. There are a number of Conservation Areas in the NCA, including village centres, as at Ollerton.

4.15 **Significant urban and urban fringe elements:** Twenty-six percent of the NCA is urban (Office for National Statistics, 2009) (ONS and others, 2004). The main urban settlements are Nottingham and its suburbs, Mansfield, Worksop and Retford. This area of Nottinghamshire continues to develop and housing growth is planned for the edge of the urban areas. There are number of urban Conservation Areas in the NCA including The Park, a fine Victorian residential estate, in Nottingham. Other significant elements of the urban landscape in

Nottingham are the broad tree-lined streets created in the nineteenth century, including Lenton Boulevard, Radford Boulevard and Gregory Boulevard.

Ecosystem services

4.16 The Sherwood landscape delivers a range of services that contribute to the economy within and outside the NCA and peoples' well-being. The most important ecosystem services identified are outlined below.

Provisioning services

4.17 **Agriculture - Mixed arable farming, pigs and poultry:** The sandy soils are mostly Grade 3 agricultural land (ADAS, 2000). Irrigation and fertiliser inputs allow them to be used flexibly for arable and vegetable farming (Defra, 2009). The NCA supports a significant amount of root crop production as the light soils allow crops to be lifted throughout the year. In particular, carrots from this area supply many UK supermarkets, and potatoes are very important for the crisp and chip markets. Outdoor pig and poultry systems are locally prominent. Pasture and dairying is chiefly limited to the area of small estates north of Worksop, though English Longhorn cattle are used to graze the ecologically sensitive wood pasture of the Sherwood NNR.

4.18 **Timber:** Private landowners and the Forestry Commission manage land in the NCA for timber production. The Forestry Commission estate at Sherwood Pines covers about 3,300 acres and is managed for recreation and wildlife conservation as well as timber. The 2005 UK Timber Forecast projected availability of 258,000 cubic metres of softwood from the combined Forestry Commission estates in Central England and 425,000 cubic metres of softwood from private sector estates in the same area (Forestry Commission, Forest Research, Forest Service Northern Ireland, 2005). Private estates in the Dukeries have large forestry elements dominated by Scots pine, Corsican pine and larch.

4.19 **Biomass and renewable energy:** Biomass can be found in the form of short rotation willow coppice. There are prominent stands of this beside the A614, and there is potential for wood chip from the extensive commercial forestry plantations or smaller woodlands. In future, short rotation forestry may be a possibility in this landscape. The area has been assessed as offering high potential for short rotation coppice and medium potential for miscanthus (Defra, 2007). Additionally, the accompanying assessment of environmental suitability within the Sherwood landscape noted that Short Rotation Coppice had the potential to complement the forest character area (Natural England 2009e). Figure 8 shows energy crop opportunity zones.

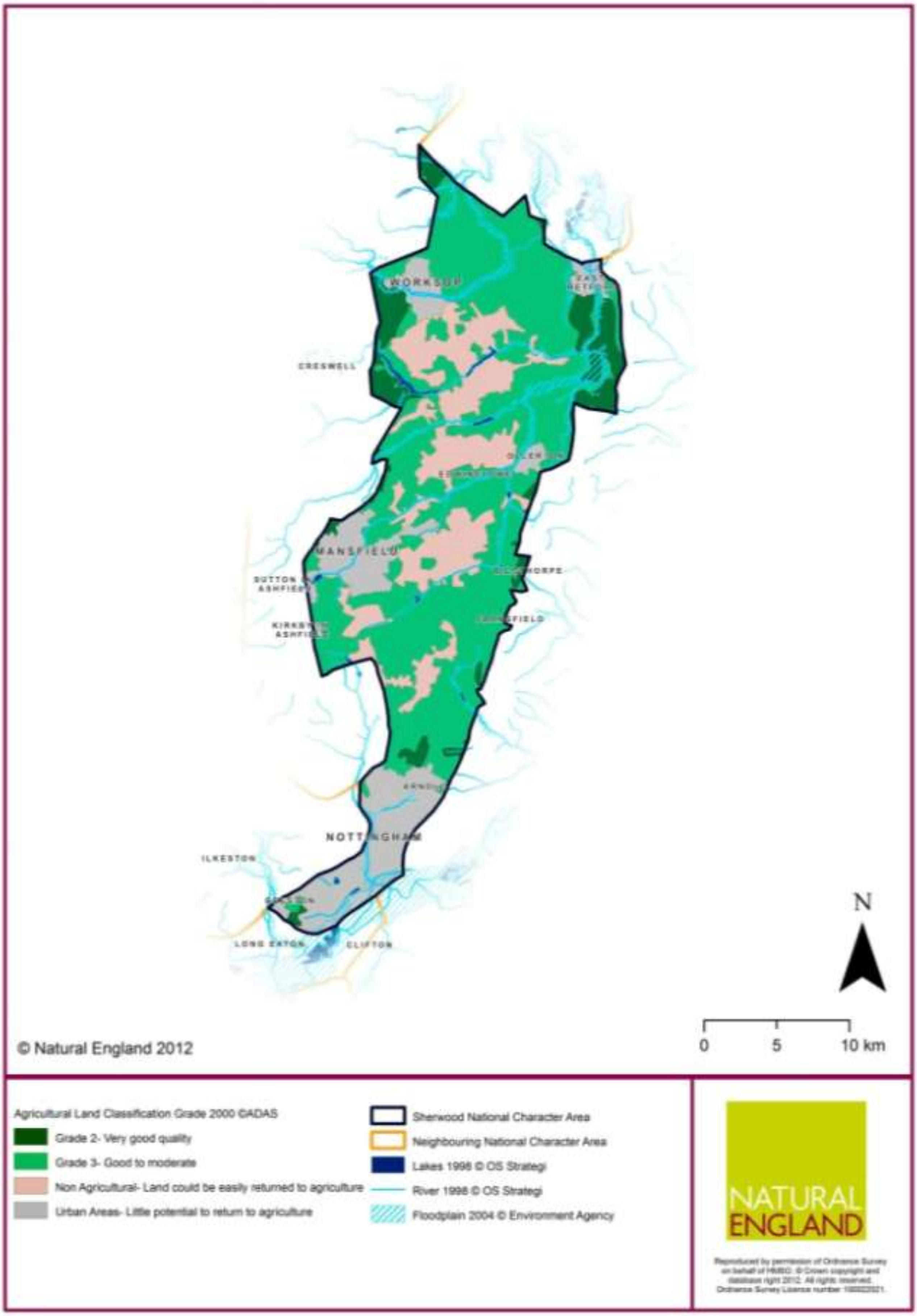

Figure 7 Agricultural Land Classification for Sherwood NCA

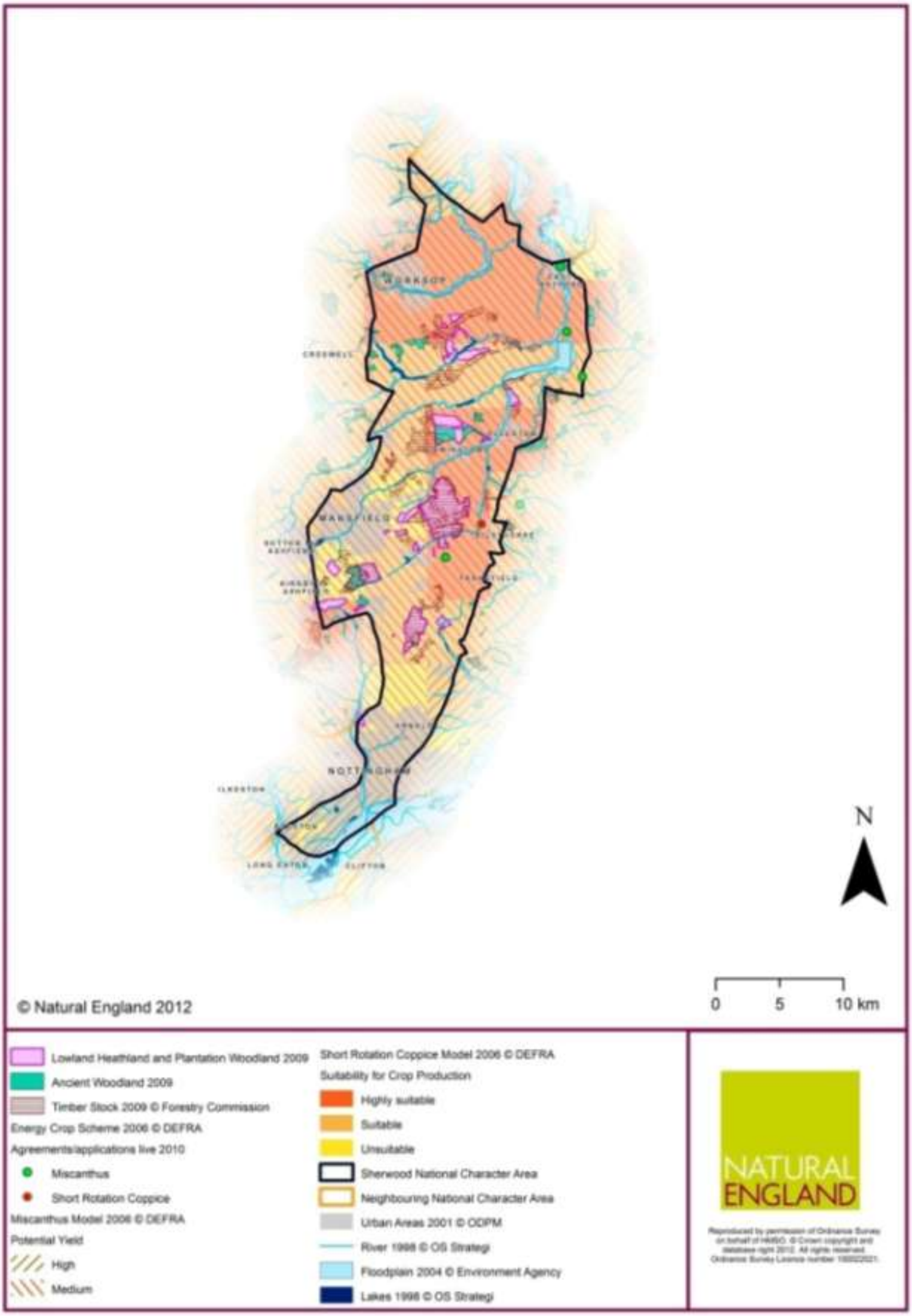

Figure 8 Timber stock and energy crop potential within Sherwood Character Area

4.20 **Minerals - coal and sandstone:** Carboniferous coal measures lie deep below the sandstone, sloping downwards towards the east, and still hold significant reserves. The mining industry is however much reduced, and now only continues from Thoresby colliery in Edwinstowe, after production at the adjacent Welbeck colliery ceased in May 2010 (UK Coal, 2010). Sandstone extraction for aggregate sand and non-aggregate silica sand remains a locally significant industry with active and dormant quarries between Nottingham and Mansfield and in the far north of the area, above Worksop (Nottinghamshire County Council, 2003).

Regulating Services

4.21 **Carbon storage:** Biomass and soils form an important carbon store. Of the biomass in the NCA, woodland, and particularly conifer woodland, is the most significant carbon store. Where woodland is managed, carbon continues to be sequestered. Heathland, wetland areas and grassland also contribute to this service. The sandy soils which cover most of the NCA have low carbon content (0-5%) and are vulnerable to carbon loss through oxidation. There are small pockets of higher carbon content soil (5-50%), likely to be associated with woodland or heath (Natural England, 2011).

4.22 **Climate regulation:** Urban and rural woodlands and trees offer a cooling effect and provide shade on hot days, and help to ameliorate the effect of high winds (Read, 2009) (AECOM/Climate East Midlands, 2010). Tree-lined roads, local parks, University and College grounds, allotments, private gardens and Local Nature Reserves contribute to this service in Sherwood's urban areas. Water also has a moderating effect on temperatures (Natural England, 2009g), (AECOM/Climate East Midlands, 2010).

4.23 **Flood alleviation:** Although flooding is not generally a major issue in the NCA as rainfall tends to soak quickly into the sandstone, it has caused significant localised damage in severe weather events (Downend, 2008). Areas alongside the rivers offer informal flood storage. Action in this NCA can also influence flooding downstream in the Humberhead Levels and elsewhere in the Trent River basin.

4.24 **Water treatment:** There is currently only one surface water body which is treated for public water supply in the Idle and Torne catchment and it is achieving good ecological status or good ecological potential (Environment Agency 2009a). Phosphate pollution is an issue for surface water. Nitrate pollution from agriculture is a current issue, which is being addressed by Severn Trent Water at a landscape scale under the AMP5 process.

4.25 Freshwater in rivers and streams also provides a regulating function by diluting (regulating) pollutants from external inputs.

Supporting services

4.26 **Fresh water:** The East Midlands Sherwood Sandstone aquifer is a key resource, providing about ten percent of all water supplies in the Environment Agency's Midlands region (Environment Agency, 2009b) and forms the main public water supply in the NCA. There is also abstraction from rivers. (Environment Agency, 2007). Water from the aquifer tends to be of high quality (Environment Agency, 2009a), though this quality is declining, hence designation of the area as a Nitrate Vulnerable Zone. This designation ensures that farmers control the use of nitrate fertilisers and manure (Environment Agency, 2007). As yet there have been no reports of aquifer contamination from mineshafts. The high usage of the aquifer, with abstraction for both public water supply and agricultural irrigation, results in low groundwater levels and low base-flows in the relatively few rivers on the surface of the landscape. Fresh water in the form of rivers, lakes, ponds and streams in the NCA supports many water dependent habitats and species. Over-abstraction is a continuing issue for rivers running through the NCA, and would need to be reduced to obtain "good status" in line with the Water Framework Directive (Environment Agency, 2007). One surface water body in the Idle and Torne catchment is also treated for public water supply.

4.27 Free draining sandy soilsThe dominant soil type in Sherwood, as mapped by the National Soils Map (Cranfield University, 2004) and shown in Table 3 and Figure 9, is freely draining, slightly acid sandy soil. Such soils have low fertility. With irrigation and fertiliser, the soils are, however, capable of supporting commercial farming.

Table 3 Soil types and areas in Sherwood NCA

Soil type	Area (ha)	Percentage
Freely draining lime-rich loamy soils	1078.9	2
Freely draining slightly acid loamy soils	1767.8	3.3
Slightly acid loamy and clayey soils with impeded drainage	4486.5	8.4
Freely draining slightly acid sandy soils	37510	70.2
Freely draining floodplain soils	535.5	1
Freely draining very acid sandy and loamy soils	1577.4	3
Naturally wet very acid sandy and loamy soils	1144.6	2.1
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	3221.1	6
Loamy and clayey floodplain soils with naturally high groundwater	1469.9	2.8
Loamy soils with naturally high groundwater	124.3	0.2
Loamy and sandy soils with naturally high groundwater and a peaty surface	314.9	0.6
Water	224.5	0.4

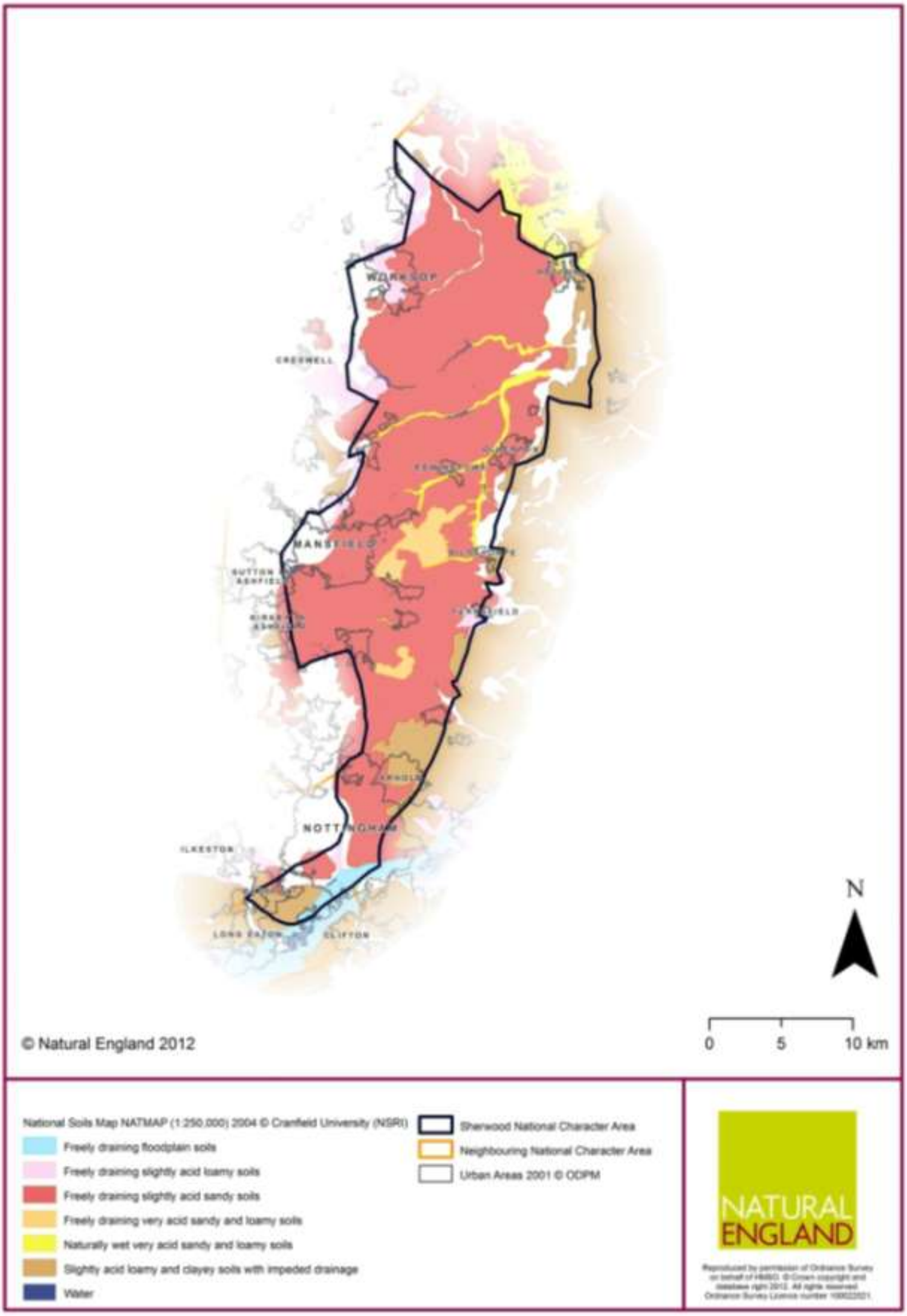

Figure 9 Soils within the Sherwood NCA

4.28 **Pollination:** Pollination by invertebrates is important for fruit crops, and importantly for Sherwood enables the continuation of rare heathland and wildflower habitats. The habitats in the NCA support a variety of pollinators. In particular, lowland heath, of which there is 3129 ha in Sherwood, contains both early (gorse) and late (heather) nectar sources (Natural England, 2004).

Cultural services (sense of place, aesthetic value, inspiration and spiritual value)

4.29 The remaining woodland and heath of Sherwood Forest is locally distinctive and gives a sense of wildness, tranquillity and isolation. Woodland in the NCA has strong associations with history, fairies and folklore (Natural England, 2009f).

4.30 In places, the landscape of Sherwood is also a resource for more general cultural knowledge about the environment. This may include formal and informal activity such as teaching children about nature, safety in woodland/by water, which mushrooms are safe to pick, or where to get blackberries. Sherwood attracts many birdwatchers, and thousands of schoolchildren attend educational events there. Altogether around 350,000 visitors go to the Sherwood Forest Visitor Centre annually (Nottinghamshire County Council, 2012). The area plays host to a great deal of community activity and environmental education, involving community groups of all sizes, and county or nationwide organisations such as the Sherwood Forest Trust, the Greenwood Community Forest and the National Trust.

4.31 The Sherwood landscape provides a context within which the history of the Sherwood area, its communities and significant personalities can be understood. Lord Byron, DH Lawrence and the Pilgrim Fathers are linked to the Sherwood area. The Dukeries provide a link to monastic history and landed gentry. The relatively recent mining history of this part of Nottinghamshire is also seen in the landscape.

4.32 Possibly the most striking cultural association of Sherwood NCA is to the story of Robin Hood. Sherwood is inextricably associated with the legend of Robin Hood, and through that legend Sherwood Forest, and the city of Nottingham, have global resonances. Places and landscape assets have particular traditional associations with parts of the story. Examples include Robin Hood's Stable, a cave at Papplewick.

© Whitfield Benson/Natural England

Plate 5 Natural inland outcrop of Sherwood Sandstone known as “Robin Hood’s Cave” on the River Maun near Walesby

4.33 A further indication of the local cultural and tourism significance of Sherwood Forest is that images of the forest, trees, and Robin Hood can be seen in the County and District Council’s branding, and other references are found in numerous business names, roads and place-names.

4.34 The oak trees of the remnant Sherwood Forest wood pasture play an important role in bringing the Robin Hood myth alive for people. These oaks also have a further cultural value, through the aesthetic beauty of mature or stag-headed oaks.

4.35 **Genetic resource and knowledge:** This is provided by veteran oaks, wood pasture lowland heathland and the biodiversity they support. Particularly valued, as the designation of these areas demonstrates, is the knowledge provided by the designated NNR and SAC, the genetic resource within the veteran oak trees, the functioning of heathland and wood pasture habitats, the extent of species distribution, and species life-cycles.

4.36 A tree nursery growing local origin seedlings from Sherwood, including the ancient oaks, is located at Sherwood Pines and run by Nottinghamshire County Council and the Sherwood Forest Trust.

4.37 The local red deer population is believed to be genetically different from other red deer in the UK, as it has a different antler pattern (personal communication, Janice Bradley, Nottinghamshire Wildlife Trust).

4.38 **Geology (scientific knowledge):** Early Triassic Sherwood sandstones and conglomerates of the Sherwood sandstone group are the most significant geological asset in the character area. They are valued as they drain freely into the underlying aquifers, and shape the landform. The Local Geological Sites (also known as Regionally Important Geological Sites) assessment for Nottinghamshire also references exposures of Mercia Mudstone group, and the waterstones of the Colwick formation (Nottinghamshire Biological and Geological Record Centre, 2004).

4.39 There are no geological SSSIs in the character area, but there are 23 sites classed as Local Geological Sites, totalling 87.7 ha, and 48 classed as Sites of Importance for Nature Conservation (SINCs, also known as Local Wildlife Sites), totalling 187 ha. Some sites are both Local Geological Sites and Local Wildlife Sites. Two significant Sites of Special Scientific Interest (SSSIs), Scrooby and Styrrup quarries, lie just outside the NCA but on Sherwood sandstone.

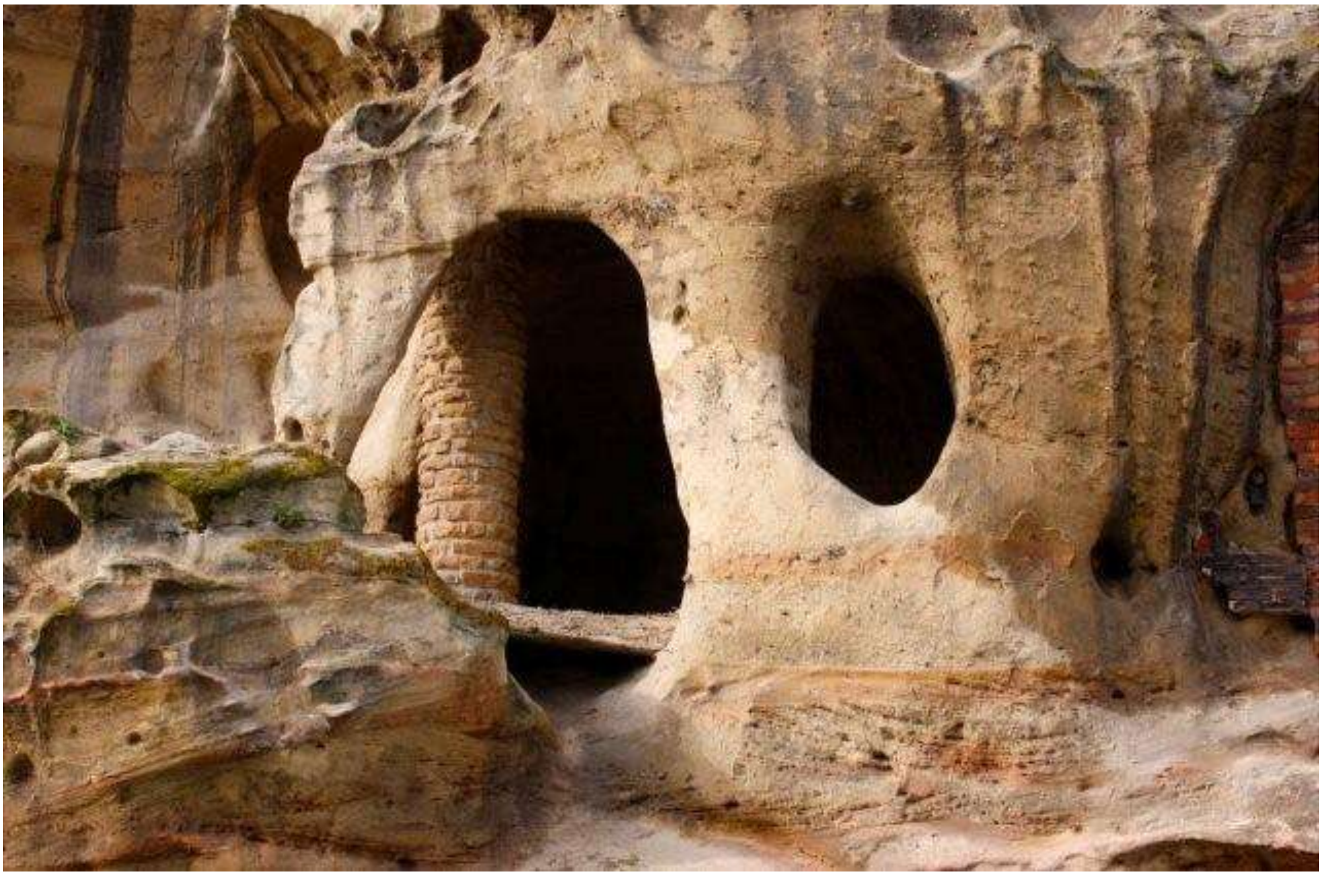

Plate 6 Detail of caves under Castle Rock, Nottingham

4.40 The main geological assets identified in the NCA are:

- **Man-made Sherwood sandstone exposures:** quarries and pits. As sandstone quarrying has been a major activity in Sherwood, there are numerous Local Geological Sites in quarries and pits. Examples include Barbers Hill Quarry, Ravenshead, Bestwood Quarry, Carlton Forest Quarry and Calverton Bestwood Quarry. The latter is noteworthy as a site with good exposures of the Nottingham Castle Formation (Bunter Pebble Beds) of sandstone.
- **Man-made sandstone exposures:** road, rail and canal cuttings. Examples include Hucknall Road Cutting, Bulwell Forest Railway Cutting (this shows the gradational boundary between the Lenton Sandstone Formation and the Nottingham Castle Formation) and Rainworth Railway Cutting.
- **Natural inland outcrops, such as river bluffs and cuttings, and *in situ* erosive features.** The most famous of these are probably the outcrops underlying Nottingham Castle, into which Ye Olde Trip to Jerusalem pub is built. Other examples include Maun River Cliff at Clipstone and the University Lake Old River Bluffs.

- **Natural and man-made subterranean features.** The best known of these are probably the caves in Nottingham city centre, which still have an important role in explaining the city's past. There is a SINC at Tunnel Road, Nottingham, which provides an excellent exposure of the Nottingham Castle formation showing sedimentary structures in three dimensions.
- **Natural geomorphological features.** Sherwood contains natural geomorphological features such as river meanders and periglacial features (meandering river patterns are characteristic of parts of Sherwood). The Druid Stone, Blidworth SINC, described as "an isolated pillar of well cemented glacial gravels standing on a base of the Nottingham Castle Formation" is an example. Further work is needed to identify where other good examples are.

4.41 **Historical knowledge:** Sherwood contains a rich legacy of past human activity. Human activity in the Sherwood area has been strongly affected by the sandy soil and lack of large rivers, and the limitations this places on settlement pattern, agriculture and industry. Evidence of prehistoric occupation exists from the Palaeolithic onwards. Notable is a large Iron Age hill fort at Old Ox Camp, one of a line of five that stretch from the Trent northwards.

4.42 There appears to have been woodland clearance for cultivation in Roman times, which is believed to be the origin of the lowland heath habitat. There is a lack of evidence for the post-Roman and early medieval period, but it is believed that much land was abandoned and reverted to scrub and woodland. Place name evidence suggests Viking and Anglo-Saxon settlement (Nottinghamshire County Council, undated). The Domesday Book describes much of the area as wood pasture, used by the surrounding settlements. Much of the area – and beyond – was taken under Forest Law in the twelfth century (East Midlands Landscape Partnership/LDA Design, 2010a). The land would have been well exploited for its goods, whether owned by king, church or community. Evidence shows that small villages and farming communities continued to manage Sherwood Forest for pasturage, pannage, and timber and other goods, and that areas of woodland and heath were converted to agriculture, in a process known as assarting. Records show that by the early 17th Century, woodland covered just 10% of the Royal Forest, with nearly 40% of the area classed as uncultivated open heathland. The remaining land was already under cultivation.

4.43 Major monasteries such as Rufford and Welbeck Abbeys also held land in the area, which passed at the Dissolution to a few large landowners. Those owners and their descendants created the large houses, ornamental parklands and landscape gardens, and planned estate villages which are characteristic features of the NCA.

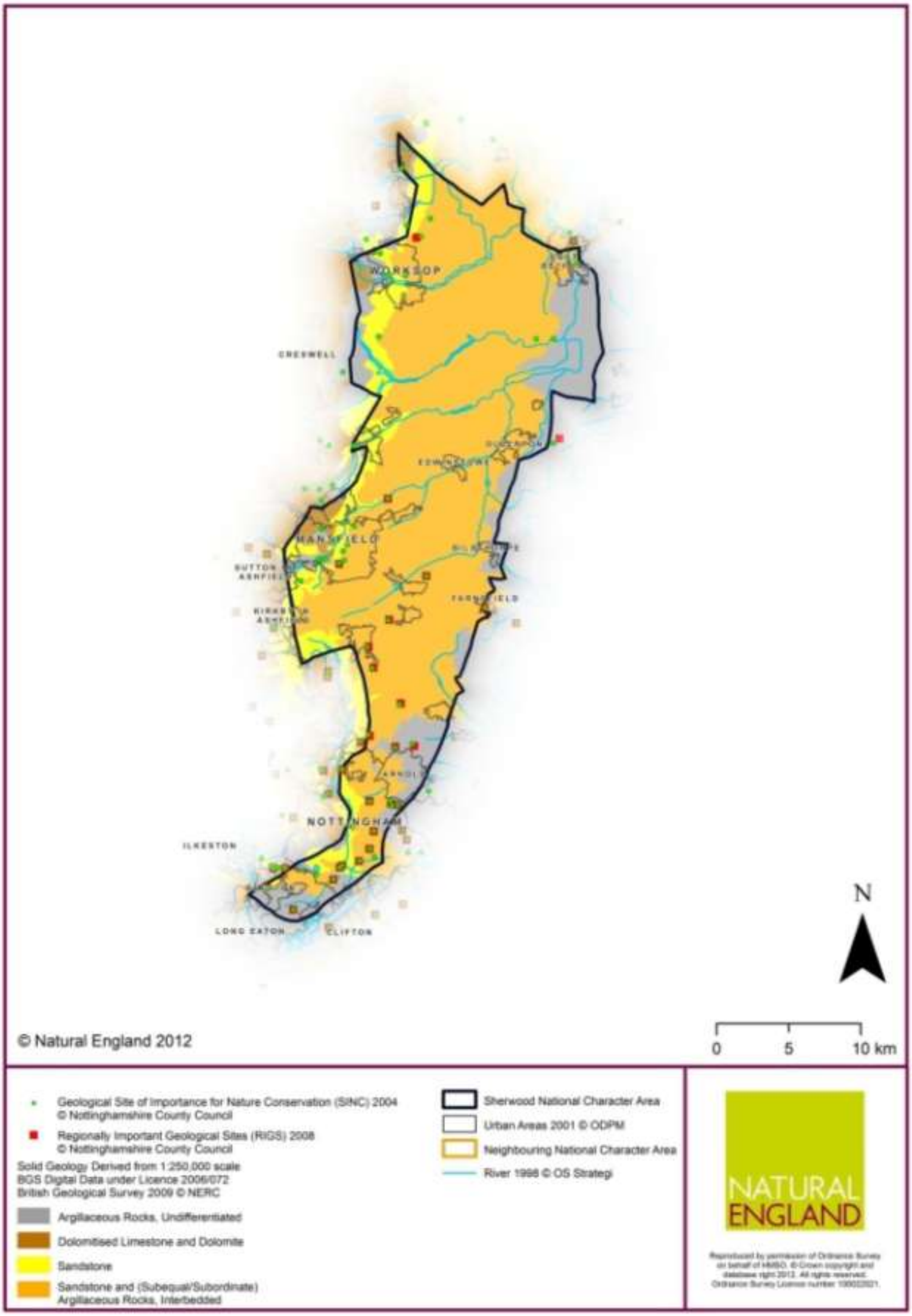

Figure 10 Solid geology in the Sherwood NCA

4.44 Parliamentary enclosure of arable land in the eighteenth and nineteenth centuries created the essence of the current field pattern. The poor sandy soil did, however, mean that farming remained difficult. At the end of the eighteenth century John Throsby wrote:

> *'The soil, is not of that nature, which may insure, at all seasons, a plentiful harvest. A hot summer is very inimical here to the growth of corn; the two preceding years, in some places, in this forest, scarcely produced the quantity of corn sown; but it may be much improved by alternately ploughing and laying down for grass, which I find is much practiced here' (Throsby, 1790).*

4.45 Deep coal mining, associated new or expanded settlements, and railway goods lines became a prominent feature in the southern part of the NCA from the late nineteenth century onwards, declining towards the end of the twentieth century.

4.46 Figures 11 and 12 show areas where there are many identified historic environment assets. The central area of Sherwood has, until recently, received relatively little attention from archaeologists. Heathland and tree cover makes it difficult to identify assets from the air, but documentary evidence and archaeological investigations in recent years, principally by Nottinghamshire County Council, suggest there is a rich archaeological record to be discovered.

4.47 The assets which contribute to historic knowledge in Sherwood include:

- Below ground historic assets - buried archaeological remains, foundations of buildings, post-holes, cemeteries/burials etc.
- Above-ground assets – such as King John's Palace.
- Parkland, for example, Clumber Park, Rufford Park, Thoresby Park.
- Traditional field boundaries and field patterns - best seen at Jordan's Castle Farm and in the Dukeries.
- Traditional buildings and structures - these include red brick farm buildings, as at Jordan's Castle Farm, Wellow, or Old Ollerton.
- Ancient or veteran trees (particularly those with cultural connections), largely found in the Sherwood NNR where there are over a thousand, and nearby at Thoresby. Many have been named, illustrating their importance to local communities.
- Subterranean archaeological/geological features, particularly caves and tunnels, for example the caves of Nottingham and at Mansfield Woodhouse.
- Portable artefacts, which may be found anywhere preserved in soil, water, or on the surface.
- Historic wetlands, including the Duke of Portland's water meadows.
- Industrial and military remains. Railway lines and mining remains criss-cross the region. Papplewick and Bestwood pumping stations provide a good example of high Victorian industrial architecture. There are also military remains, including defence exercise areas from the First World War and Second World War Prisoner of War camps. Ordnance stores and associated infrastructure were in place on the current NNR.
- Polite architecture/buildings and estate villages - there are numerous examples from periods from the sixteenth to nineteenth century, including Clumber Park, Thoresby Hall and Stables, Wollaton Hall, Nottingham Castle and the estate villages.
- Conservation areas - including Ollerton, planned urban or suburban areas such as The Park, a Victorian suburb of Nottingham, and urban centres such as the area around Nottingham Castle.

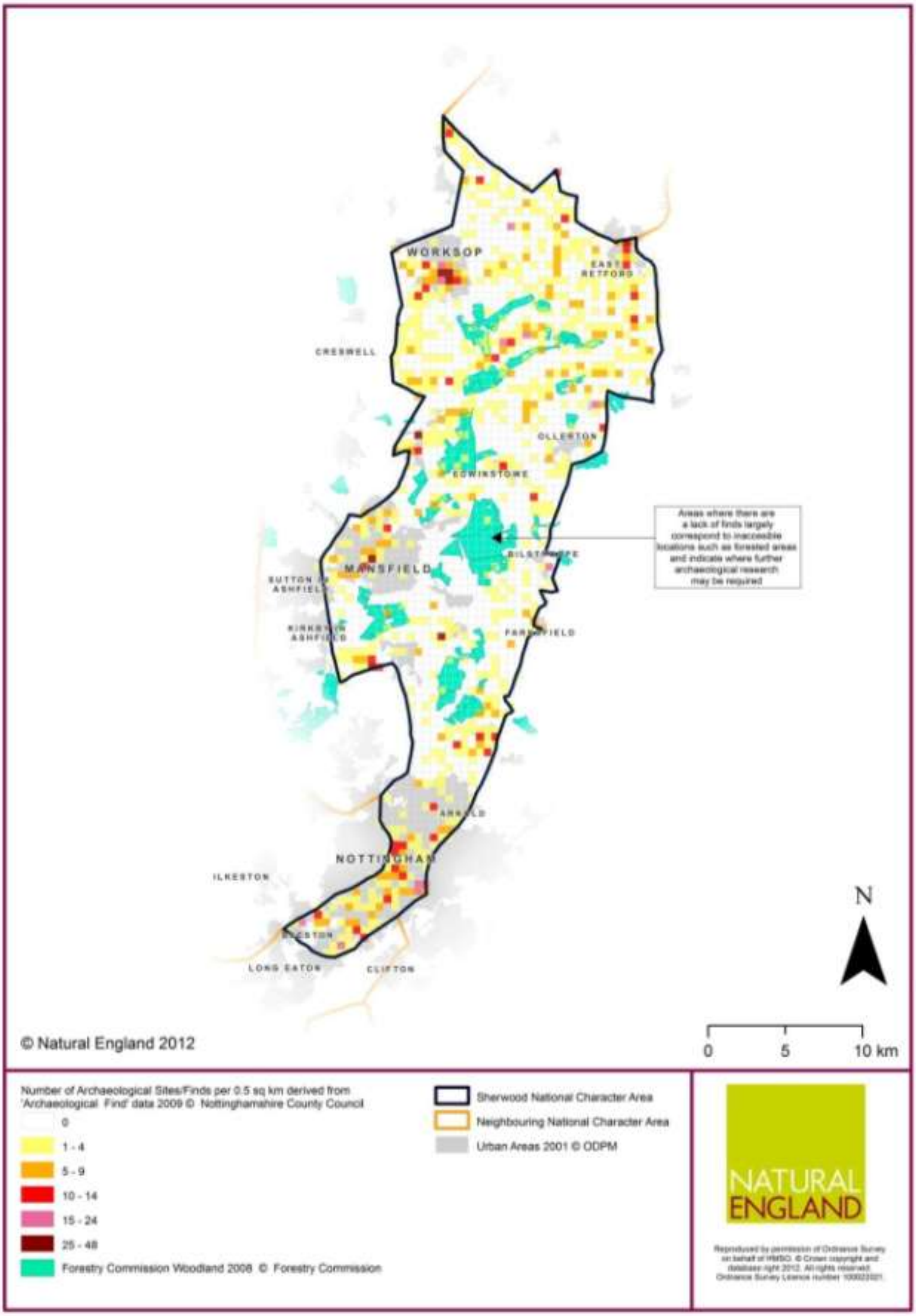

Figure 11 Distribution of archaeological sites and finds in Sherwood NCA

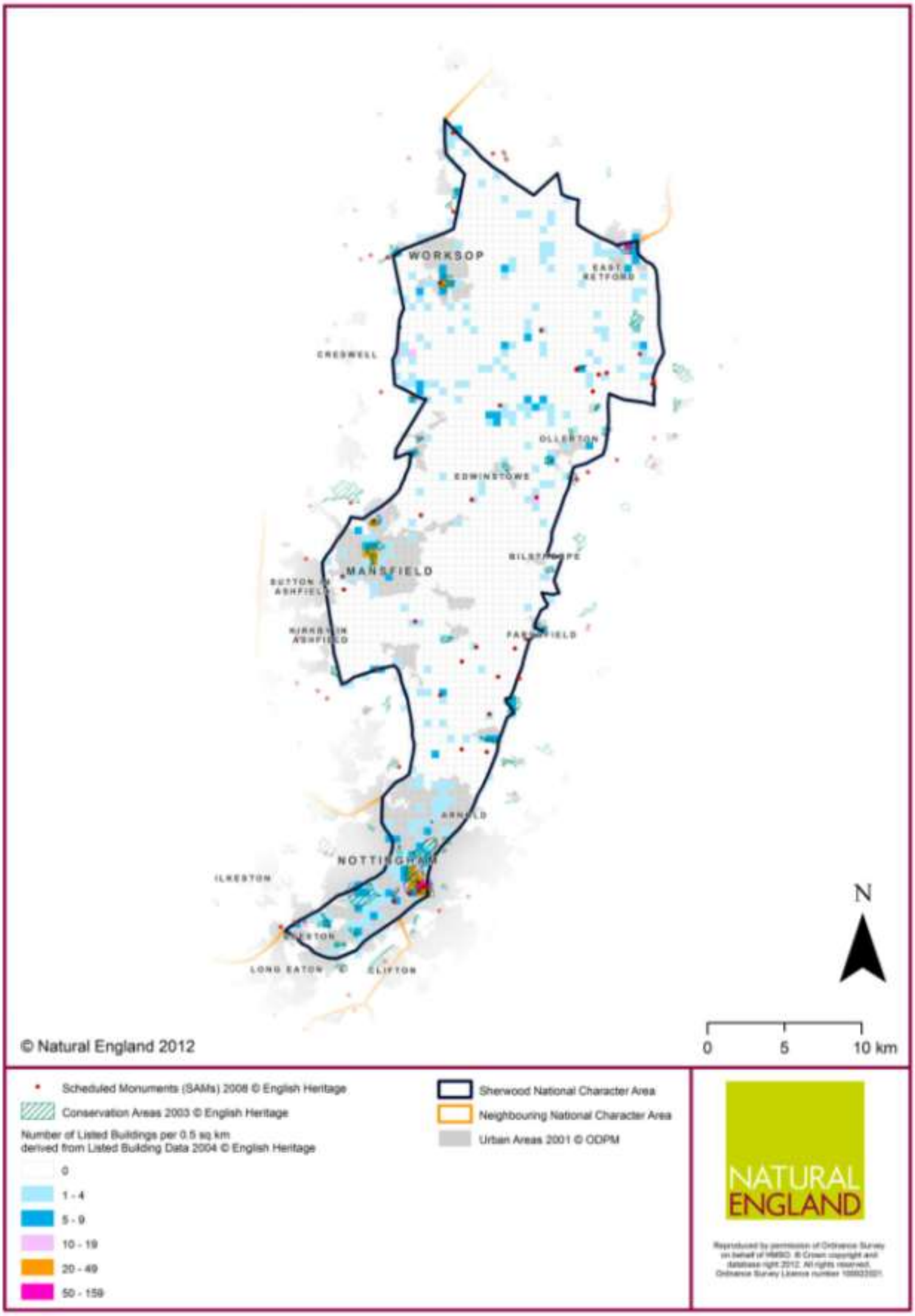

Figure 12 Distribution of Listed Buildings, Conservation Areas and Scheduled Monuments in Sherwood NCA

4.48 **Recreation and Tourism:** Tourism is an important cultural service here. People are attracted to the East Midlands as a whole for the link with Robin Hood. Many people visit the remaining core of Sherwood Forest and the Dukeries, Sherwood Pines, the Center Parcs holiday park, the Sherwood Forest Visitor Centre, Country Parks and NNRs, and Clumber Park and the other Dukeries estates. Visitors to the rest of the Sherwood NCA may be drawn because of connections to the Pilgrim Fathers or DH Lawrence, the attractions of the city of Nottingham, or visits to historic buildings and gardens.

4.49 There are 391 km of public rights of way and 69 km of cycle routes in the NCA. There are fewer rights of way in the centre and north of the character area (Figure 13), reflecting the historic pattern of large estate ownership. However, this area is where much of the 220 ha of open access land registered under the Countryside and Rights of Way Act, and part of the accessible Sherwood Forest NNR, can be found. Additional accessible woodland is found as part of the Forestry Commission and Dukeries estates. Examples include Clipstone Forest, Birklands and Bilhaugh (part of the NNR) and Budby Corner. There is only a small amount (4 ha) of common land. There are nineteen Local Nature Reserves (LNRs).

4.50 Recreation also occurs around the water bodies, canals and rivers in the area. Sailing is found at Kings Mill Reservoir, and angling is popular in lakes and rivers. The Chesterfield Canal runs across the NCA from Worksop to Retford, before turning north towards Gainsborough. Fishing, boating and walking along the canal are all popular.

4.51 Many visitors come relatively short distances. Sherwood is the "back garden" for a very large population; it is easily accessed from Nottingham, Mansfield and Doncaster, the South Yorkshire conurbation around Sheffield, and eastern Derbyshire. The Monitor of Engagement with the Natural Environment (MENE) report (Natural England, 2010d) that around half of all the quarter of a billion recreational visits to green space that took place in the East Midlands in the period surveyed were within two miles of the starting address, and while 48% of these were to countryside locations, 41% were to urban parks and amenity green spaces. Local green space is important and both urban amenities and the facilities of the wider countryside are well used and highly valued.

4.52 As over a quarter of the character area is urban, urban green space is an important element of access and recreation. It ranges from large areas such as Wollaton Park, to cemeteries, Local Nature Reserves, green corridors and back gardens. Publicly accessible designed landscapes are found in both urban and rural areas, for example, at Nottingham Arboretum, Church Cemetery, Newstead Park, Welbeck and Thoresby Estates. There are also a number of "new" amenity landscapes that have arisen out of the restoration of former coal workings and colliery sites. Facilities such as Vicar Water Country Park and Rainworth Water Local Nature Reserve are well used and play an increasingly important part in the mix of public access and recreation assets.

Biodiversity

4.53 The biodiversity of Sherwood underpins the majority of landscape characteristics and ecosystem services within the NCA as well as being important in its own right. For a relatively urban area, Sherwood NCA contains a wide range of important UK Biodiversity Action Plan (BAP) habitats. The BAP habitats identified here are those which, in consultation with the Sherwood Habitats Strategy Group, were considered to make the most significant contribution to the landscape character and ecosystem services of Sherwood.

4.54 Figure 14 shows that some areas of the NCA offer coherent ecological networks, as in the areas of wood pasture, parkland and heath between Edwinstowe and Worksop, and the mixed habitat assemblages offered by the Clumber Park, Thoresby Lake and Welbeck Lake SSSIs. Habitats are more fragmented south of Farnsfield, and in the sandstone estatelands to the east of Worksop.

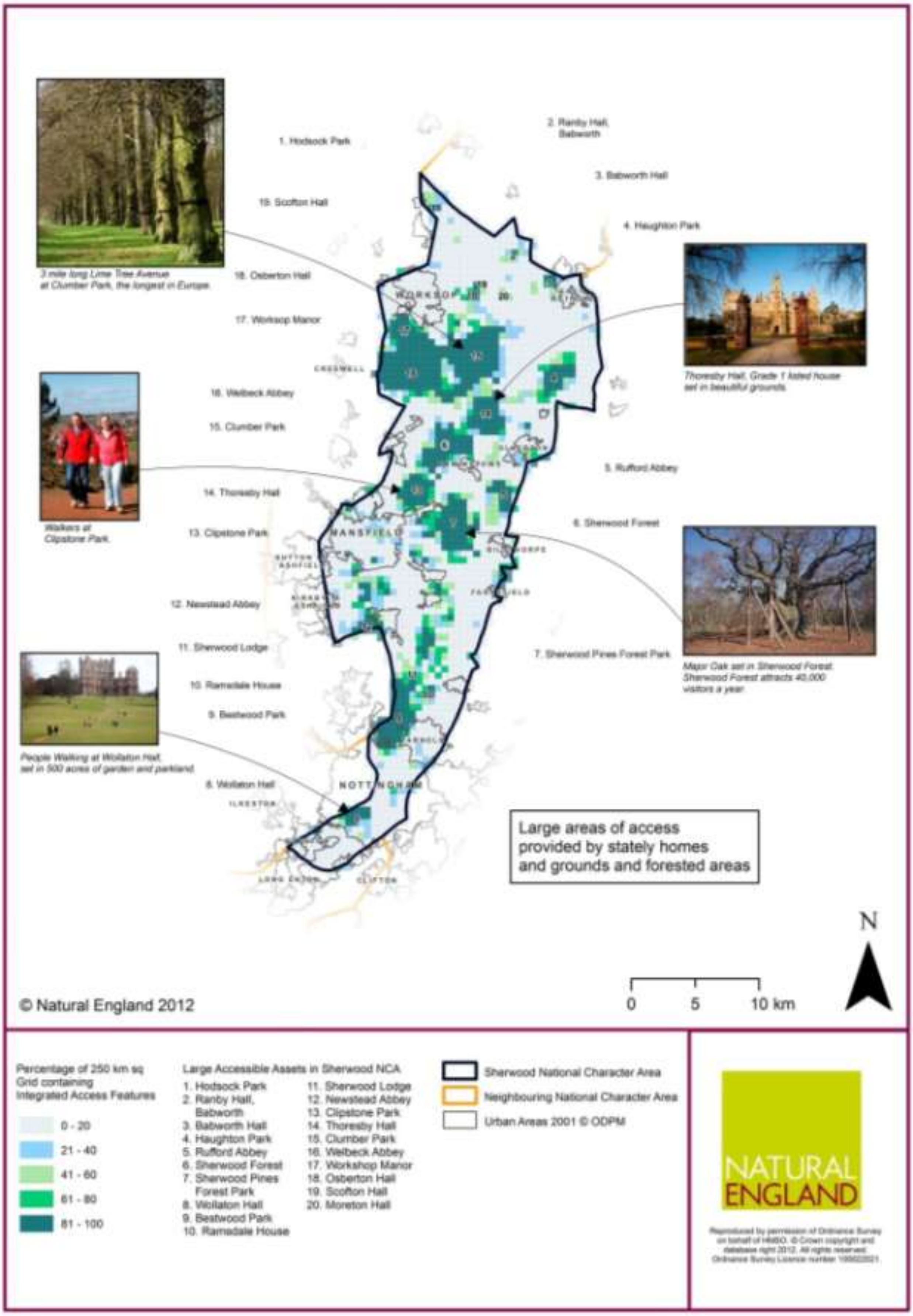

Figure 13 Distribution of access and recreation assets in Sherwood NCA

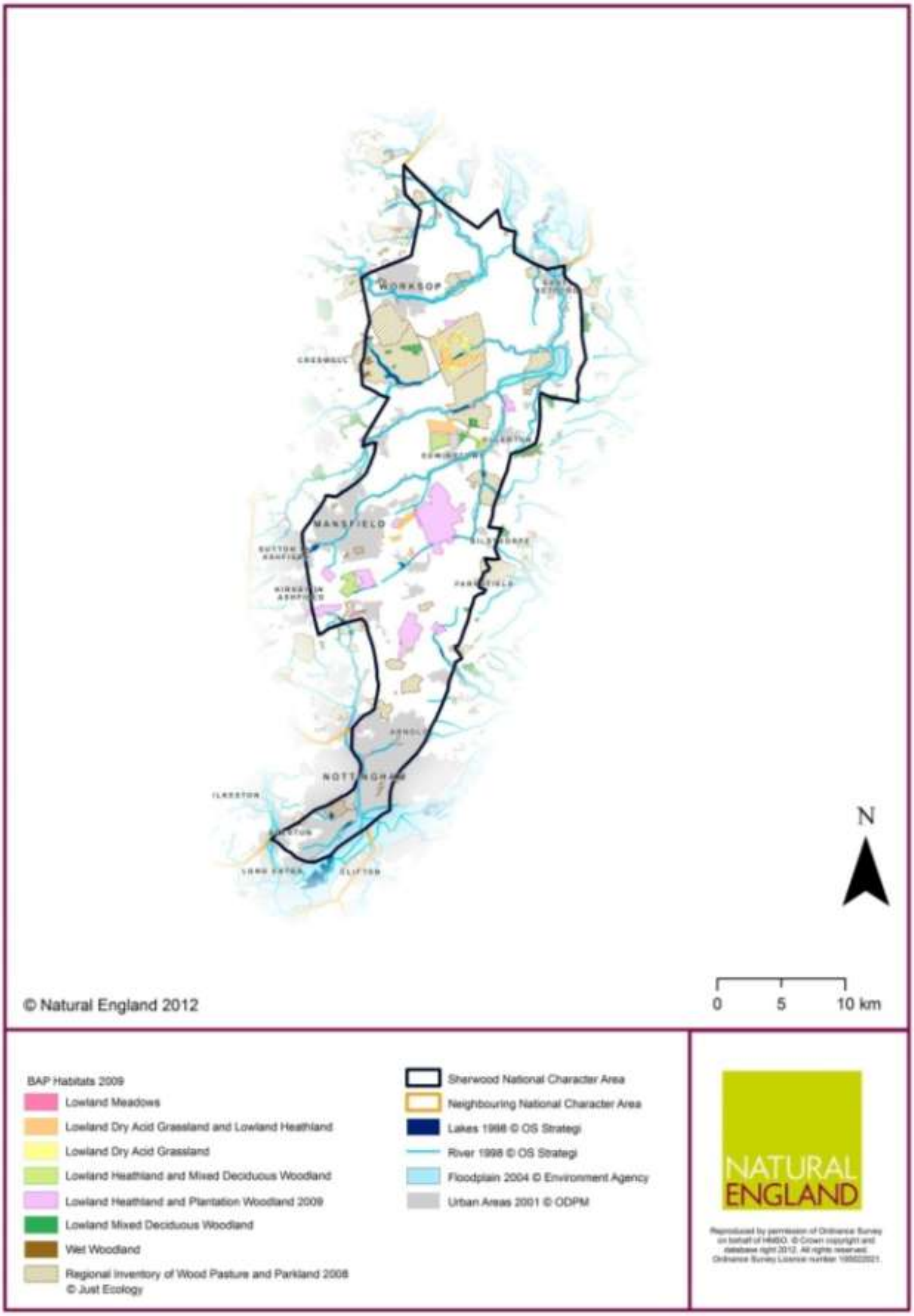

Figure 14 BAP Habitats in Sherwood NCA, with additional information on wood pasture and parkland

4.55 Designated sites in Sherwood NCA (Natural England 2010a, Natural England 2010b):

Internationally important sites:

Birklands and Bilhaugh SAC – 270.065 ha. This forms part of the Sherwood Forest NNR.

Nationally important sites:

Sherwood Forest NNR - wood pasture, lowland heath, 423.6 ha.

Eleven SSSIs, totalling 1746 ha, fall largely or fully in the NCA:

- Birklands and Bilhaugh - 507.8 ha, remnant of the historic Sherwood Forest and contains the best examples of oak-birch woodland in Nottinghamshire together with tracts of acid grassland and heath.
- Birklands West and Ollerton Corner - large area of former pasture-woodland with a rich beetle fauna and associated areas of acid grassland and heath.
- Clipstone Heath - dry acid lowland heath.
- Clumber Park - 526.59 ha. The park comprises one of the largest expanses of semi-natural vegetation in Nottinghamshire. It is made up of relict ancient woodland, historic parkland and extensive grass heath with rich invertebrate, bird and bat communities.
- Rainworth Heath - wet and dry heath; invertebrate fauna.
- Rainworth Lakes - some of best acidic marsh and open water plant communities remaining in Nottinghamshire and is of regional importance.
- Sherwood Forest Golf Course - 62.5 ha lowland heath (large single block).
- Strawberry Hill Heaths - Dry acid lowland heathland.
- Thoresby Lake - 58.13 ha site, fine examples of dry acid grassland, acid-loam grassland, marsh & reedswamp plant communities. These, together with an area of open water, comprise one of the best mixed habitat assemblages on acidic soils in Nottinghamshire. The lake is artificial, lying in the valley of the River Meden.
- Welbeck Lake - 104.47 ha site, habitats centred on Great Lake and Carburton Dams. There is a notable breeding bird community, including Nottinghamshire's biggest heronry and winter wildfowl communities. There are artificial lakes along Poulter and Millwood Brook. Associated broadleaved, conifer and mixed plantations are found together with the lakeside reedbeds.

Locally important sites:

There are twenty-one LNRs, totalling 268.5 ha and 242 Local Wildlife Sites (formerly Biological SINCs) , totalling 7056 ha (although some of these overlap other LNRs, SSSIs, NNR) (Nottinghamshire Biological and Geological Record Centre, 2004).

Selected key species:

Pedunculate oak Quercus robur, Sessile oak Quercus petraea, Red deer Cervus elaphus, Noctule bat Nyctalus noctula, Leisler's bat *Nyctalus leisleri, W*oodlark Lullula arborea, Nightjar Caprimulgus europaeus, oak polypore fungus Piptoporus quercus, Brown trout Salmo trutta and water vole Arvicola amphibius.

Lowland acid grassland

4.56 This habitat is typically found on free-draining, nutrient poor sandy soils such as those in Sherwood. Here, it sometimes forms a mosaic with lowland heath. Characteristic plant species include wavy hair grass *Deschampsia flexuosa*, sheep's fescue *Festuca ovina* and red fescue *Festuca rubra*. A range of animals such as reptiles, invertebrates and birds including woodlark *Lullula arborea* need the open aspect provided (BRIG (ed. Ant Maddock), 2008).

Plate 7 Acid grassland in the foreground, by Clumber Lake and church

Lowland fens

4.57 A very limited resource, generally found along the rivers because the water table is so low.

Wood pasture and parkland with ancient trees

4.58 Ancient trees are located through the area, largely as isolated individuals or as groups within open areas of grass heath or woodland. Key sites include Clumber Park, Thoresby Park and Haywood Oaks. Sherwood Forest NNR supports the largest area of ancient wood pasture in the NCA and the greatest concentration of ancient and veteran trees. The NNR comprises the ancient forest of Birklands and contains more than a thousand ancient oaks *Quercus petraea, Quercus robur*, most of which are known to be more than five hundred years old. The most famous of these, the Major Oak, may be nearly twice that age.

4.59 The NNR and Clumber Park are considered to be among the most important sites in Britain for its decaying-wood invertebrate fauna. Nearly one thousand species of beetle have been recorded in the NNR. Forty-nine species of beetle present are nationally rare or scarce, with many primarily associated with hollow cavities and decaying heartwood of mature oaks. Over two-hundred species of fungi have been recorded; the most notable being the rare oak polypore *Piptoporus quercus*, a UK Biodiversity Action Plan species. Local birdlife includes the tawny owl *Strix aluco*, redstart *Phoenicurus phoenicurus* and tree-creeper *Certhia familiaris*. The area also supports a number of bat species, including the Noctule *Nyctalus noctula* and Leisler's *Nyctalus leisleri* (Natural England, 2010b) (Natural England 2010c) (Steve Clifton, Natural England, personal communication).

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Plate 8 Veteran trees form a key element of the Sherwood NNR

Lowland heath

4.60 This habitat forms a broadly open landscape on impoverished soil, characterised by the presence of plants like common and bell heather *Calluna vulgaris, Erica cinerea*, and gorse *Ulex europaeus*. Notable is the locally occurring hoary heath, which has abundant grey hairs and is a sub-species of common heather (personal communication, Janice Bradley, Nottinghamshire Wildlife Trust). Lowland heath is a dynamic habitat, and without management it can quickly revert to scrub and ultimately woodland. Heath is important for a range of breeding birds such as the tree pipit *Anthus trivialis*, woodlark *Lullula arborea* and nightjar *Caprimulgus europaeus*, and for invertebrates, including a significant number of UKBAP priority species such as the forester moth *Adscita statices*. There were once very large areas of dry heathland in the Sherwood NCA. It is now very fragmented but important remnants are found, with some relatively large areas in the NNR as at Budby. There are some very small and ecologically important areas of wet lowland heath, which include cross leaved heath. In recent years, lowland heath has been successfully re-created as part of post-mining restoration, as at Vicar Water Country Park, and along roadside verges, such as the Rainworth Bypass. An extensive resource of viable heathland seeds remains under the conifer plantations managed by the Forestry Commission near Edwinstowe, and after felling the lowland heath regenerates naturally.

Wet woodland

4.61 This is a limited but important resource in Sherwood, typically lying close to the rivers. It is dominated by alder *Aldus glutinosa* and willow *Salix alba*, with occasional native black poplar *Populus nigra*, a county rarity.

Lowland mixed deciduous woodland

4.62 This is a key habitat within Sherwood and is relatively widespread. It is relatively impoverished in species diversity, characterised by oak *Quercus robur* and *Q. petrea* and silver birch *Betula pendula*, intermixed with species such as holly *Ilex aquifolium* and rowan *Sorbus aucuparia*. Sweet chestnut *Castanea sativa* and Scots pine *Pinus sylvestris* are often scattered through the stand. There is a distinct lack of understorey vegetation, which is often dominated by bracken *Pteridium aquilinum*.

Plate 9 River Poulter at Clumber

Deep lakes > 1 ha including oligotrophic and dystrophic lakes, mesotrophic lakes and eutrophic standing lakes

4.63 Lakes are found in the parks in the north of the region, including Clumber, Thoreseby and Welbeck and along the rivers Poulter and Maun. These lakes are all SSSIs. At present, nitrate and phosphate pollution means that most lakes are likely to be eutrophic. However, as the underlying geology of the rivers is low in nutrients, there is the potential for the lakes to reach oligotrophic or mesotrophic status.

Rivers and streams

4.64 The Maun, Meden and Poulter are the main rivers in a not very well watered area. They are an important habitat for water vole *Arvicola ambhibius* and brown trout *Salmo trutta*, but are vulnerable to pressures such as nitrate and phosphate pollution and development (Environment Agency, 2007).

Non-BAP priority habitats

4.65 In addition to the habitats listed above, the following habitats contribute to the biodiversity of Sherwood: road verges; brownfield and restored sites; gardens and hedges; farmland; and ponds. Managing these to maintain a mosaic of healthy habitats will also be a key part of maintaining the landscape of Sherwood.

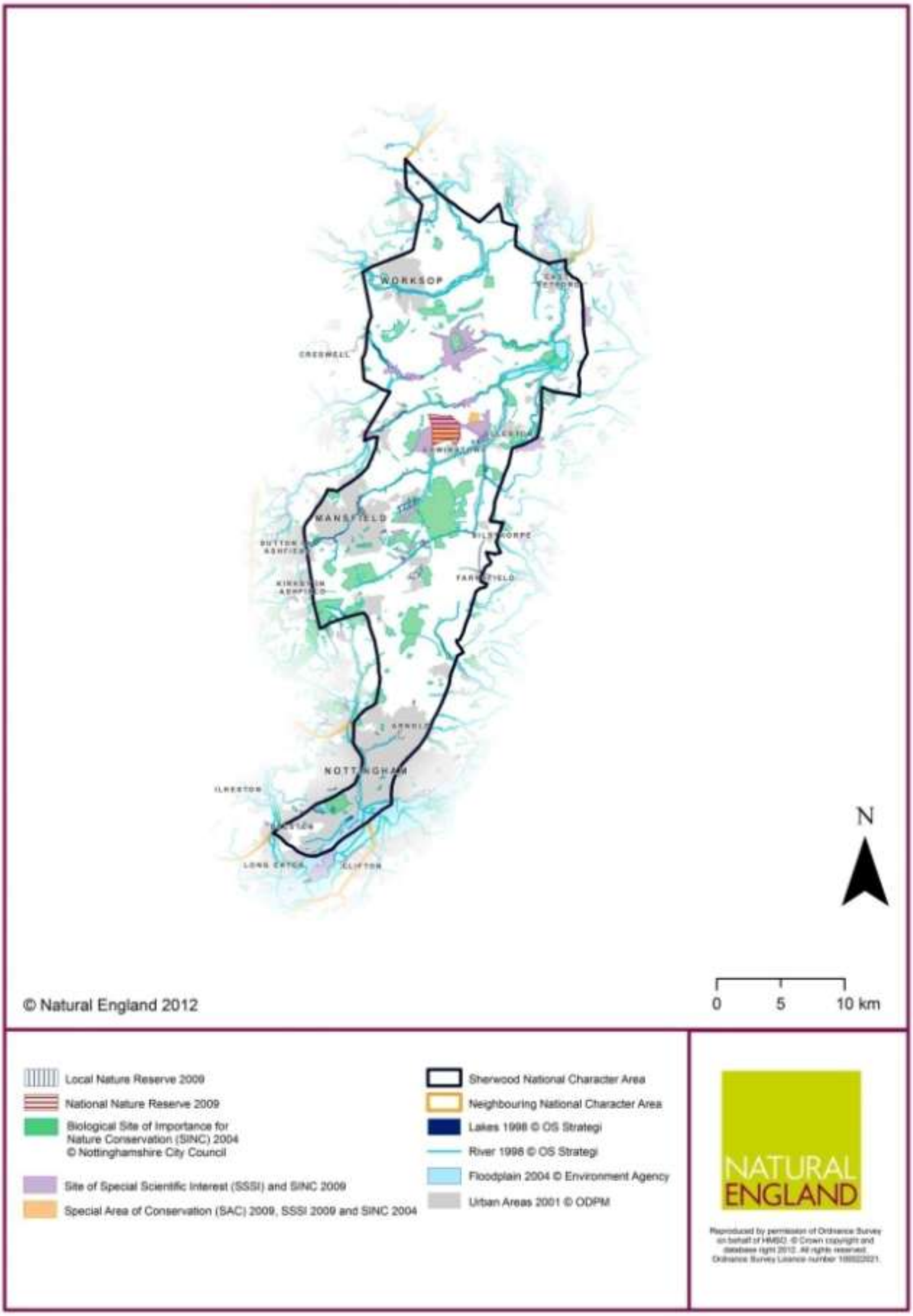

Figure 15 Designated Biodiversity Sites

Part 2 – Results of vulnerability assessment

4.66 This section summarises the assets in each category – geology and soils, habitats, areas for recreation, and historic environment – that were deemed to be 'more vulnerable' or 'moderately vulnerable'. Detailed tables of results, including assets assessed as having relatively low vulnerability, can be found in Appendix 3.

Geology and soils

More vulnerable

4.67 Soils are the most vulnerable asset in this section. Healthy soil is made up of organic matter and organisms as well as minerals. For soil to function well, all these elements need to be maintained. We found that both soil formation and maintenance of healthy soil condition would be more vulnerable to predicted climate trends. Soils may be vulnerable to changes in agricultural practice or cropping as farmers adapt to climate change and to economic changes. However, improvements in farming techniques could benefit soils.

4.68 Soil erosion is already a significant issue in parts of Sherwood. Prolonged periods of drought may result in significant moisture and nutrient loss, resulting in erosion, or wind-blow, and increased carbon loss. Similarly, extreme weather may result in increased run-off of soil from exposed areas (for example, agriculture) onto roads and into watercourses and lakes.

4.69 The consequences of soil loss or damage are significant for many of the services Sherwood provides, perhaps most notably agriculture, habitats, water quality and conservation of historic assets. These in turn are likely to impact on the cultural services Sherwood provides.

Moderately vulnerable

4.70 Sandstone Quarries and pits were assessed as moderately vulnerable to climate change, because of sensitivity of quarry faces to repeated wetting and drying, and increases in erosion, balanced against the relative ease of undertaking monitoring and adaptive management in managed quarries.

4.71 Table A in Appendix 2 summarises the vulnerability of geological and soil assets in Sherwood to the impacts of climate change.

Habitats

More vulnerable

4.72 In our analysis, most BAP habitats were classed as more vulnerable to climate impacts. Many of the habitats identified as more vulnerable include areas designated for their biodiversity interest. Loss of, or changes to, habitats and species, whether due to climate trends or other factors, might undermine the basic purpose of designation.

4.73 **Lowland heathland** is vulnerable for a number of reasons. Lowland heath is already under pressure in this area from elevated nitrogen deposition levels, which may make it more vulnerable to climate pressures (Nottinghamshire Wildlife Trust, 2011). A longer growing season and dry summers are thought to favour bracken growth and scrub development. A further threat from projected hotter drier summers is fire, which can temporarily damage heathland and kill its wildlife and, in the case of a deep burn, destroy the seed bed (Fraser *et al.*, 2009).

4.74 However, lower soil fertility, which is a possible consequence of soil damage due to climate change, could benefit heathland as it allows heathers to out-compete grasses. There are suggestions that insect pests may become more common in response to warmer weather and longer breeding seasons. Heather beetle can be a significant problem for heathland, and research into beetle populations might be helpful (Pautasso *et al.*, 2012).

4.75 An issue for both heathland and grassland is the apparent increased competitive advantage of bracken in the Sherwood area. Currently, cold periods and frosts knock back bracken growth, causing stunting and sometimes death. Warm, wet springs increase its viability and vigour, increasing its coverage at the expense of slower-growing, shorter, heathland and grassland species (Fraser *et al.,* 2009). Anecdotal reports from those working on Sherwood's heathland habitats suggest that these impacts are already being observed, as bracken control programmes have to be enhanced in response to increased bracken growth (personal communication, Sherwood Habitats Strategy Group, 2010).

Plate 10 Bracken competing with lowland heath at Oak Tree Heath near Mansfield. Picture copyright Sherwood Forest Trust

4.76 **Wood pasture and parkland with ancient trees:** Veteran and ancient trees have survived many changes in climate in the past. However, they are now already under stress due to their age and size. The impact of climate trends is likely to exacerbate those stresses. Increased storminess and high winds may damage or fell trees. Drier summers may put trees under water stress, and dry, compacted soil around trees will make it harder for rain, when it does fall, to reach the root system. Wetter winters may also result in soil damage. It has been suggested that novel pests and diseases may increase as the climate warms (Ray, Morison and Broadmeadow 2010). Trees that are already stressed due to climate pressures are also likely to be more vulnerable to attack by endemic pests and diseases. A decline in numbers of veteran trees would reduce the wood pasture habitat for which the Birklands and Bilhaugh SAC is designated. There is a gap of some three hundred years in the age of younger trees (personal communication Steve Clifton) and as such the current stock of veterans, which provide invertebrate habitat and cultural value, is irreplaceable. This study has not examined the consequential impact on invertebrates and fungi for which veteran trees are the host, of changes in their micro-habitat such as increased summer dryness.

4.77 **Freshwater and fen habitats:** These appear highly vulnerable to climate change. In particular, drier summers and the consequent impact on water flow, quality and habitat health are major issues (Clarke 2007).

4.78 **Lowland fens and Wet woodland:** The small remaining areas of these ecological communities within the NCA are highly sensitive to drought if groundwater falls too low. Adaptive capacity is limited because of the small areas remaining, and re-creation is highly dependent on the availability of water of an appropriate quality throughout the year. Active management may also be needed for water meadow areas.

4.79 **Deep lakes, mesotrophic lakes, rivers and streams:** Hotter, drier summers, combined with low groundwater levels, are a major issue for these habitats. All are very sensitive to pollution, eutrophication and algal bloom. There is capacity for recovery if water quality is good enough but water pollution is currently a significant pressure on the health of these habitats in the NCA. Dry summer periods increase the risk of nutrient concentration within lakes and streams, and therefore of eutrophication. It is also suggested that the changing climate may result in increased competition from invasive species, to which cold water species are particularly sensitive (Clarke 2007).

Moderately vulnerable

4.80 **Lowland acid grassland and mixed woodland** were felt to have greater adaptive capacity than the communities and land cover types above. The lowland acid grassland in Sherwood already tends to be composed of relatively drought tolerant species. It is likely that increasingly dry summers and a longer growing season would result in a change in floral species composition towards the most drought tolerant species and a greater proportion of annuals but not a loss of the habitat, which might increase at the expense of other habitats. The impacts on current fauna are more difficult to assess as it can depend on features at the micro scale such as shade, aspect and soil dampness as well as tolerance limits of individual species. Some species with specific needs may find their niche disappears; others will benefit.

4.81 **Lowland mixed deciduous woodland** was also assessed as moderately vulnerable to the impacts of climate change as it is likely to persist even though compositions of species change. Management techniques are also well known. However, pests and diseases are likely to become a more serious issue in a warmer, wetter climate which provides more favourable conditions for fungal and bacterial pathogens. It might also be assumed that tree insect pests would have a greater likelihood of survival in warmer winters and be able to reproduce more frequently during a longer summer season.

4.82 Table B in Appendix 2 summarises the results of the vulnerability assessment for habitats.

Historic environment

4.83 The historic environment is a resource which cannot be replaced once lost or fully repaired once damaged. Our assessment indicated that a number of key historic environment assets in Sherwood are vulnerable to climate change impacts. The impacts of climate change tend to increase the pressures on assets that are already vulnerable to existing threats. The impacts of climate change seem to create few opportunities for the historic environment.

4.84 The vulnerability of historic environment assets is essentially site specific because of the diverse range of assets, each in a unique situation with its own characteristics. However, it is useful to identify how broad types of historic assets might be vulnerable to the impacts of climate change.

4.85 In assessing vulnerability, it was assumed that current good practice approaches to the historic environment will be maintained. The level of designation of historic assets is recognised as being low, with perhaps 95% of archaeological assets unprotected by designation. Scheduling and listing excepted, historic environment designations offer very limited legal protection. For other historic assets, preservation relies largely on businesses and government following good practice. If good practice is not followed, the consequential vulnerability of all historic environment asset types to climate change impacts would be substantially increased.

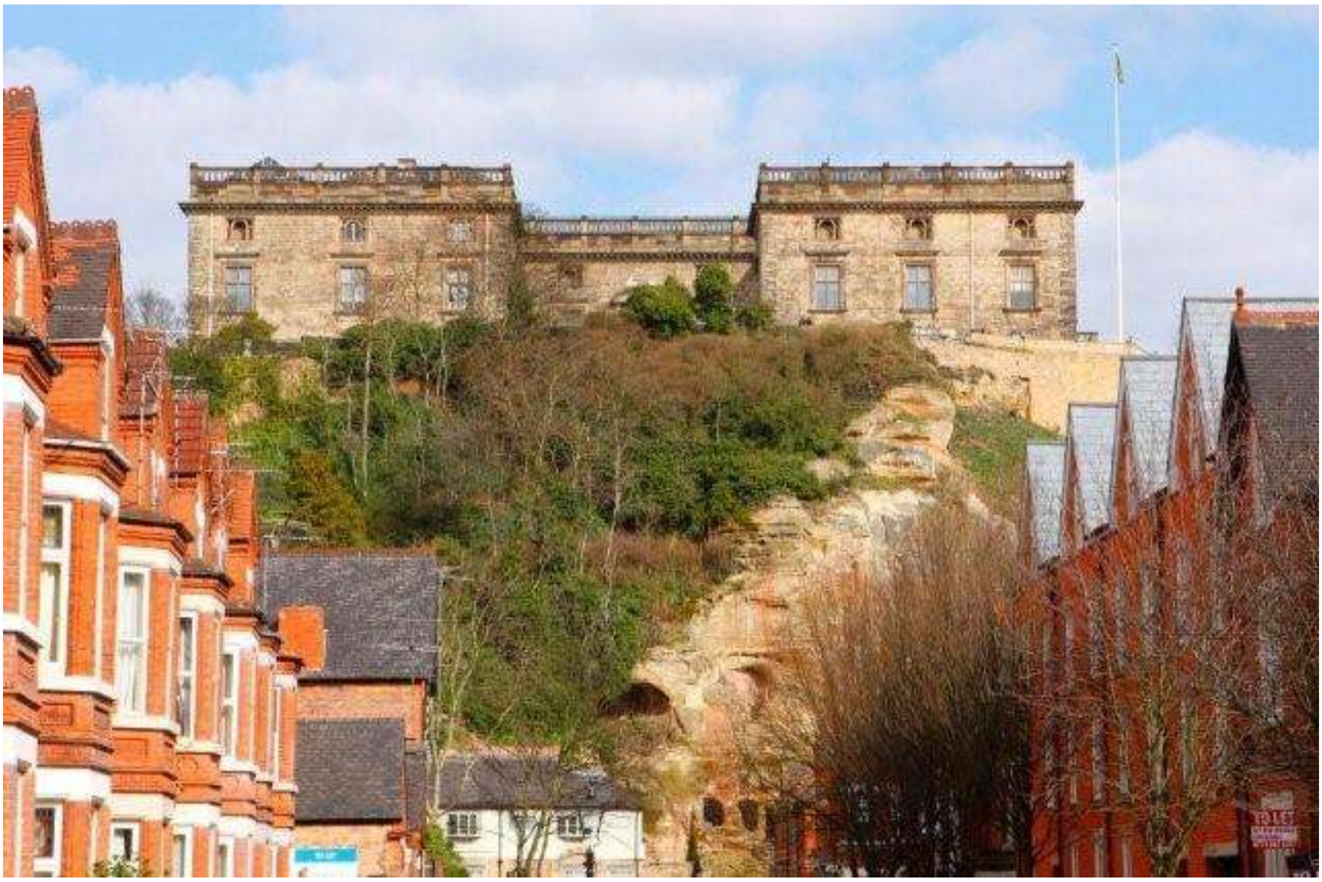

Plate 11 Nottingham Castle on its sandstone outcrop, with caves, overlooking urban residential development below

4.86 Historic environment assets may be vulnerable to indirect impacts of climate change and the adaptation responses of other sectors. Increased pressure on food production and more use of biomass could lead to an intensification of arable cultivation and an increase in energy crops in previously grassed areas. This could put pressure on historic assets preserved in grassland settings and may compromise the ability to preserve above ground assets such as earthworks. Parkland management is also dependent on viable grassland management.

4.87 Many key historic environment assets in Sherwood are natural or semi-natural features, for example the veteran trees of Sherwood Forest and the designed parkland and water meadows.

More vulnerable

4.88 **Below ground historic assets:** Each asset is a unique record and there is limited capacity for management. Buried deposits preserved anaerobically by waterlogging are sensitive to drying out, particularly where peaty deposits remain as for example along the River Maun. Other damage may be caused by soil erosion either due to drier summers, intense rainfall events or wetter winters. The acid sandy soils found in most of the Sherwood NCA are identified earlier as highly vulnerable to climate change.

4.89 **Parkland:** A significant element of the value of historic parkland is in the remaining design and layout, and in factors such as the form of the trees chosen when the parkland was planted. Parkland trees may be particularly sensitive to storm damage and to novel pests and diseases, and native beech is known to be particularly sensitive to hot dry conditions (Broadmeadow and Ray, 2005; National Trust, 2005). Damage to or loss of veteran trees may be particularly significant in designed parkland because programmes to replace trees may encounter difficulties due to the aesthetic difference between the species likely to thrive and those intended when the area was designed. This could have an adverse impact on the historic and cultural quality of the parkland. Features in the landscape such as ha-has, ice houses and grottos may be vulnerable to erosion, weather damage and increased scrub growth.

4.90 **Ancient or veteran trees:** The vulnerability of veteran trees is discussed in the habitats section above. In Sherwood NCA, many of these trees have important cultural and historic associations, either as part of designed parkland in the Dukeries or as part of the remnants of the royal forest of Sherwood associated with Robin Hood.

4.91 **Historic wetlands including water meadows:** Historic wetlands are semi-natural features which are sensitive to drying out, which in turn may result in the loss of evidence preserved in anaerobic conditions. The low groundwater levels discussed in the habitats section above reduce the adaptive capacity of these areas.

4.92 **Polite architecture/buildings** in Sherwood, which are particularly important in the Dukeries area, are likely to be "more vulnerable" to climate change. These assets are likely to be particularly sensitive to climate impacts because of the age and fragility of materials used. An increase in intense rainfall events could overwhelm original rainwater goods and result in damp and flooding within buildings (National Trust, 2005). If larger rainwater goods are installed, externally visible changes to the appearance of houses, and a loss of some historic character will result, which causes particular difficulty for listed buildings. There may also be an increase in pests affecting the external and internal fabric of buildings, and of fungal infections, which may increase in warmer wetter winters. The vulnerability of historic buildings to the impact of climate change mitigation and carbon reduction measures, such as solar panels and double glazing installation, was not assessed as this was beyond the remit of the study. However, it is recognised that these matters are of significant concern (Council for British Archaeology, Climate East Midlands, East Midlands Heritage Forum, 2010).

4.93 **Conservation areas:** As with polite architecture, risks from heavy rainfall, and from the impact of mitigation measures are judged to make the appearance of conservation areas within Sherwood more vulnerable as a result of climate change.

Moderately vulnerable

4.94 **Traditional buildings and structures, earthworks and port able artefacts:** These were assessed as moderately vulnerable to climate change. The impacts on soils which have been identified elsewhere will significantly affect the vulnerability of historic assets below the surface of the soil, earthworks and portable artefacts. Additionally, adaptive changes in farming practice or cropping in response to climate change, if they involve ploughing of previously fallow areas might increase the risk to earthworks and portable artefacts.

4.95 Table C in Appendix 2 summarises the results of the vulnerability assessment for all historic environment assets.

Access and recreation

4.96 Changes in climate are considered very likely to affect patterns of recreation. Hotter, drier summers may result in an increase in visitor numbers, particularly to areas offering shade, such as woodland. There may also be a shifting pattern of use: more visitors to parks and green spaces in early morning and late evening for example. Impacts on access and recreation assets are therefore something people are likely to notice.

More vulnerable

4.97 **Water bodies** in Sherwood are limited in extent and distribution and in their use for access and recreation. Smaller lakes and ponds which are used for recreation may be vulnerable to direct impacts of climate change such as low water levels, eutrophication and algal blooms in warm weather (Clarke, 2007). Silting and flash flooding could occur during wetter winters or as a result of extreme rainfall, and these in turn could alter their amenity value to visitors. Water bodies will also be vulnerable to indirect impacts of climate change, such as increased visitor demand and non-climate related pressure such as unauthorised swimming/boating.

4.98 The biological features of **Special Areas of Conservation, National Nature Reserves and Local Nature Reserves** are vulnerable, to varying extents, to a range of impacts (see habitats section above). People frequently visit designated sites in order to see these special interest features. The impacts of climate change may undermine the basic purpose of designation and therefore their value to visitors. Where features are very rare, there can be little scope for alternative options for people to experience or learn from them. The veteran oaks of Sherwood are an example of such a feature. In particular, Nottinghamshire County Council provides facilities at the Sherwood Forest Visitor Centre to allow people to visit the Major Oak close by easily. The Visitor Centre receives 350,000 visitors a year (Nottinghamshire County Council, 2012).

Moderately vulnerable

4.99 **Rights of way and linear assets** are extensive and very variable in nature in terms of topography and structure, and this diversity reduces their overall vulnerability as a group. However, individual paths can easily be damaged by erosion during drought periods or heavy rainfall. Paths can also become obscured by vegetation growth. The Nottinghamshire Local Climate Impacts Profile (Downend 2008) reports that rights of way maintenance has experienced the impact of increased vegetation growth due to warmer, wetter winters.

4.100 **Open access land** and **accessible woodland** were also assessed as moderately vulnerable, although there is some variability in vulnerability due to the location of these woodlands. As managing access is a human endeavour, we see opportunities for managers to change their approach in response to climate change. In the Nottinghamshire Local Climate Impacts Profile (NLCIP) it is reported that the woodland management season in country parks and conservation areas has reduced as wildlife is active for longer (Downend 2008). This suggests that where woodland is managed, it will need to be done more intensively in a shorter period.

4.101 The NLCIP identifies increased fire risk during drought periods as an existing issue in the area. Access and recreation assets, particularly **open access heath land**, are likely to be vulnerable to fire. In some cases, access to the natural environment can increase fire risk. During the heatwave of July 2006 there were seventeen separate arson incidents in Bestwood Country Park (Downend, 2008).

4.102 Table D in Appendix 2 summarises the results of the vulnerability assessment for assets which contribute to access and recreation in Sherwood.

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Plate 12 Enjoying the water at Vicar Water Country Park

Other natural resources

More vulnerable

4.103 A natural resource asset of particular vulnerability is the Sherwood Sandstone aquifer. Climate change projections (2080s, Medium emissions scenario) indicate similar annual average rainfall for the East Midlands as now, but rainfall will be concentrated in winter or in intense rainfall events. This is likely to make it more difficult for the aquifer to recharge, exacerbating lower water levels (base flows) in streams and rivers.

4.104 Surface water sources are also likely to be vulnerable to climate change. Water resources are likely to be depleted in summer. Drier summers and flood events could also lead to decreased water quality. Demand for water is likely to increase in hotter, drier summers, leading to increased pressure on water resources.

4.105 These water resource pressures have significant adverse impacts on many other elements of Sherwood's landscape character and services.

4.106 Pollinators are also thought to be more vulnerable to climate change, as lowland heath, a key habitat for pollinators within Sherwood, is more vulnerable.

Moderately vulnerable

4.107 The effect of climate change on agriculture, food and energy crops is complex, with both benefits and adverse impacts identified. Climate change is only one driver of change in the agricultural sector, which is much influenced by other social and economic factors. Important local factors are the sandy soils in the NCA, which are likely to be increasingly vulnerable to erosion and consequent nutrient loss in drier summers and during intense rainfall, and pressures on water availability as root crops are likely to require increased irrigation during drier summers. As discussed earlier, the aquifer underlying Sherwood is currently over-abstracted. In addition, where a relatively small range of crops is grown as currently in the Sherwood NCA, production may be more vulnerable to extreme weather, pests or diseases and other impacts of climate change. Temperature changes and water availability are expected to affect the timing of planting and harvesting crops and their quality (National Farmers' Union, 2005). Of the typical crops in Sherwood, carrots could benefit from higher temperatures. Potatoes may be able to be left in the ground for longer if frosts begin later and yields may improve (National Farmers' Union, 2005).

4.108 Agriculture is in general highly adaptive to different soil conditions, availability of nutrients, and water in general. This suggests that changes in soil condition and water availability, combined with changes in length of the growing season and precipitation patterns, may lead to changes in agricultural practice. There may be opportunities to grow different crops. such as maize or short rotation coppice. Different crops may alter the appearance of the landscape. Should tall crops such as maize or short rotation coppice be grown more widely, the enclosed feeling currently provided by hedgerows in the landscape could be lost. Hedgerows are also likely to be directly vulnerable to drought and to pests and diseases.

4.109 Table E in Appendix 2 summarises the results of the vulnerability assessment for natural resource assets in Sherwood NCA.

Part 3 – Potential major changes to landscape character, ecosystem services and biodiversity, and possible adaptation actions

4.110 This section summarises the major changes to character, ecosystem services and biodiversity in the area that could occur as a consequence of cumulative changes to assets deemed to be at least 'moderately vulnerable'. It considers, in turn, six areas where climate-induced change is likely to be of greatest significance.

- Sandy, acid soils.
- Water resources.
- Woodlands.
- Heathland.
- Historic landscape, historic buildings and archaeological record.
- Access and recreation.

4.111 Possible adaptation options are suggested for each set of changes. The section concludes by identifying strategic actions to build resilience and reduce vulnerability.

4.112 A full list of potential changes to each individual element of landscape character, ecosystem services biodiversity identified during the study is included in Appendix 4.

Changes to sandy acid soils

4.113 The rolling landform and distinctive orange sandy soils are a key element of Sherwood's landscape. While the landform itself may not need to adapt to climate change, Sherwood's sandy acid soils in particular were identified as more vulnerable to climate impacts. This could result in changes to agriculture, and timber production, as well as increasing risks to the preservation of many historic environment assets and the important cultural services that the latter provide. Human access and recreation would also be affected because of the impact of erosion on footpaths and waterways.

4.114 Suggested adaptation actions to address the vulnerability of Sherwood's sandy acid soils, and the services they support, to the impacts of climate change include:

4.115 In agriculture:

- Increase size of small woods in intensive agricultural areas to act as wind breaks and prevent soil drift and potentially erosion.
- Promote good hedgerow management, and create shelterbelts and other field boundary features that will reduce soil loss.
- Consider changing land use (for example, from arable to grass) where risk of soil erosion is high and soils are being lost (typically on steeper or long unbroken slopes).
- On pasture, ensure good vegetation cover and avoid over-grazing and trampling, or damage by mechanised activities.
- In the longer term, switch to crops that are less reliant on irrigation, and, more generally, to crops which respond well to new climatic conditions.
- Adopting soil moisture conservation measures, possibly through environmental farming schemes and management plans for designated sites.

4.116 Other adaptation actions are about maintaining existing good environmental practice in the management of soils to prevent run-off and wind blow and improve soil condition, such as:

- Enhancing levels of soil organic matter.

- Maintaining good soil structural condition and avoiding soil compaction or poaching, which will restrict rooting.
- Using a minimum tillage approach to reduce nutrient loss and erosion.
- Putting buffer strips in place to reduce soil loss during heavy rainfall.
- Taking measures to keep soil *in situ* when ploughing, such as contour ploughing on slopes.
- On cultivated land, considering wind breaks, nurse crops or straw planting to minimise wind erosion.

4.117 Similar soil conservation measures can be considered for paths at risk of erosion, and for the historic environment. For buried historic features, a key standard conservation measure is to revert areas that are currently ploughed to grassland, and this is partly to reduce erosion risk.

4.118 At a larger scale, soil loss through run-off during heavy rain may be reduced by managing the catchment to slow the throughput of water, using measures such as increasing tree cover, reducing the extent of bare ground and hard surfaces.

Changes to water resources

4.119 As noted earlier in the report, the provision of freshwater from the Sherwood Sandstone aquifer is expected to be more vulnerable to climate change, because drier summers and more intense rainfall in winter may make it more difficult to recharge the aquifer. Similarly, water abstraction from rivers will be increasingly difficult in low summer flows. Any reduction in water supply is likely to be combined with higher demand for water in summer, increasing pressure on water resources in the NCA. This could have significant consequential effects on agriculture. A reduction in water and interacting effects of lower levels, higher temperatures and existing pollution would affect the fen, wet woodland, water meadow and freshwater ecological communities and small water bodies that are a key feature of Sherwood's landscape in the relatively few places where they are found. Temporary, or possibly permanent changes such as loss of wet woodland, could alter the character of the NCA. Fish populations, including brown trout, would be significantly adversely affected by low flows and increased pollution.

4.120 Water bodies in Sherwood play a role in climate regulation and flood alleviation, services which could become more important if summers become hotter and there are more intense rainfall events. Pluvial and fluvial flooding currently are local issues in Sherwood, but may become more significant with more intense rainfall events and so the importance of natural flood storage could increase.

4.121 Suggested actions to address the vulnerability of water resources in Sherwood to the impacts of climate change and support adaptation include:

To manage water resources (quality and quantity) for people, agriculture and habitats:

- Promote water-efficiency in developments and by consumers across the region, thus reducing pressure on the Sherwood aquifer.
- Adopt water-efficient irrigation techniques.
- Relieve soil compaction caused by inappropriate land management practices to increase water infiltration.
- Increase on-farm water storage to collect heavier winter rainfall and reduce the need for abstraction from the aquifer and river sources, for crop irrigation purposes, during dry periods.
- Increase water retention through the catchment by increasing tree cover and reducing the extent of bare ground and hard surfaces. Severn Trent Water is developing many

catchment scale land management initiatives in Sherwood to protect ground water from nitrate, funded through Asset Management Period 5, which should contribute to this.

- Employ land management practices and consider, where economic and practical, the introduction of different forms of land cover to reduce pollution which has particularly adverse impacts on habitats and water quality at times of low flow . These may include buffer strips to prevent sediment polluting watercourses or impacting on adjoining land; planting energy crops by water courses (low input, stay in place for a number of years, slow run-off and reduce pollution but may make a visible change in the landscape).

To manage vulnerable and culturally important riverine and wetland habitats, and to take opportunities to increase resilience by increasing the extent of these habitats within the NCA:

- Increase resilience of deep lake ecosystems and other wetland areas by reducing pressures on them such as nutrient or sediment loads and introduction of non-native plants and species.
- Restore and modify lake habitats to enhance structural diversity.
- Maintain existing habitat by maintaining water levels in those areas.
- Realise opportunities for wet woodland habitat creation along streams and rivers in agricultural landscapes to reduce pollution run-off, for example, Poulter, Maun, Meden and Rainworth Water.
- Establish storm-water storage capacity for both urban areas and smaller scale for agricultural areas, particularly along the Idle and Torne catchments. Use this, and other flood management schemes as opportunities to recreate wetlands and fen.
- Encourage use of Sustainable Urban Drainage Systems (SUDS) in new and existing developments to increase flood resilience and maintain water levels within local watercourses, as well as enhancing biodiversity and strengthening intrinsic landscape character.

Where historic wetland areas remain, the archaeological deposits are likely to be increasingly vulnerable and unable to adapt to drying out:

- In remaining historic wetland areas, increase research, survey and recording of archaeological and palaeo-environmental deposits, to inform and prioritise future management or recording.

Changes to woodlands

4.122 Woodlands are among the most important natural features in Sherwood, for the biological diversity they support and their central role in the Sherwood Forest landscape. Their vulnerability to a range of the impacts of climate change, as outlined above, could have serious consequences for the character of Sherwood, the biodiversity it supports and the ecosystem services it provides.

4.123 Overall, the wooded character of the landscape is likely to change slowly. Woodland assets are likely to remain a key part of the landscape, even as subtle changes occur, such as changes in tree species, and earlier greening of woodland.

4.124 However, this overall assessment masks different degrees of vulnerability for individual trees, woodland types, and ecosystem services (such as carbon storage and local climate regulation) to which woodland contributes. Wet woodland and ancient woodland, both key habitats within Sherwood, were identified as particularly vulnerable. The veteran oak trees and wood pasture are of most concern because their vulnerability to climate change combines with an importance for biodiversity which is recognised at a European scale, and a worldwide cultural importance because of the association with the legend of Robin Hood.

4.125 A loss of trees could therefore have a significant impact on the natural values of this NCA. The Forestry Commission suggests that the composition of woodland managed for timber may change over time, though timber production is likely to continue.

4.126 This study has identified that there are a number of opportunities to use trees and woodland positively to help human communities in Sherwood NCA adapt to climate change, and maintain the important role of trees and woodland in carbon storage and climate regulation, and to enhance landscape character. Woodland opportunity mapping (East Midlands Landscape Partnership, 2010b) suggests that the landscape has good potential to support increased woodland and there are opportunities for adaptation to enhance the wooded character of Sherwood and the multiple benefits it would provide.

4.127 Suggested adaptations for wood pasture and veteran and ancient trees and their associated habitats, as at Sherwood NNR, Clumber Park and Thoresby:

- Introduce risk based fire management plans for wood pasture and particularly high value assets such as the Sherwood oaks, aimed at protecting assets and maintaining public access.
- Maintain grass heath vegetation around trees to maintain moisture within the soil.
- Make use of lightning conductors and non intrusive bracing systems to reduce risks to ancient trees, due to increased storm threat.
- Consider increased stabilisation management of ancient trees (for example, crown works to increase root-crown ratio) to reduce risk of wind-blow.
- Ensure that competing trees are removed from around ancient trees. Most of the best veteran trees are grown in open areas.
- Develop further the native tree nursery at Sherwood Pines to ensure survival of trees of local provenance.
- Improve management around existing known veteran trees, ensuring that there is no cultivation, browsing or barking of trees, and reduce fertilisation and pesticide use in the area. Alternatively, consider aerating or make use of mulch around key ancient trees, taking account of invertebrate interest.
- Identify any further unknown veteran trees in the landscape and log them on a shared data base to ensure they are maintained.
- Plan to support the next generation of ancient trees by maintaining the health of mature oak trees.
- Allow fallen trees and decaying wood to remain *in situ* where practicable to maintain habitat for key invertebrates.

4.128 In addition, there are a number of actions that constitute good woodland management practice and are not specific to climate change adaptation, but which will reduce the vulnerability of woodland areas in general and maximise opportunities for woodland and trees in Sherwood in a changing climate. These include:

- Registering seed stands and recording them on a local origin database.
- Avoid soil compaction or poaching around trees and woodland caused by inappropriate land management, which will restrict rooting.
- Increase vigilance for pests and diseases in all woodland.
- Plant tree species that are likely to tolerate predicted future climates. This will require consideration of how, where and whether trees could be replaced with more climate change tolerant native or introduced species of trees (Ray, Morison and Broadmeadow, 2010).
- Consider greater use of mixed planting, particularly for timber crops, as single species plantations are more at risk of total crop loss due to pests and diseases (Read, 2009).

- Promote the use of in-field and boundary trees, parks and wood pasture as potential shade.
- Bring woodland areas into management for their role as carbon sinks and in flood alleviation. In particular, consideration should be given to creating wet woodlands along rivers as part of flood alleviation programmes, as wet woodland is an increasingly small but characteristic element of Sherwood's landscape, and a BAP habitat.
- Increase connectivity of individual woodland stands.
- Look for opportunities to use Short Rotation Forestry in Sherwood NCA.
- Maintain the existing urban treescape and plant new urban trees to increase shade.
- Increase the use of natural vegetation in built schemes and landscaping (for example, green roofs, trees and shrubs) to increase shading and to absorb heat.

Plate 13 Outdoor pigs in foreground of wooded landscape at Perlethorpe

Changes to heathland

4.129 The vulnerability assessment indicated both positive and negative potential effects of climate change on heathland. Climate change may benefit heath as low soil fertility, as a result of erosion, could allow heathers to out-compete grasses. However, a longer growing season and dry summers are thought to favour bracken growth and scrub development, which could lead to a decline in traditional heathland plants such as gorse and broom. In addition, a potential move away from pine to broad-leaved species in commercial forest plantations in response to climate trends may also reduce the area of heathland. The heathland seed bank survives well in commercial pine plantations and regenerates when pine is felled, but after a few years of broad-leaved woodland, typically, the soil no longer supports heathland habitat. This suggests that the implications of climate change for this important element of the traditional Sherwood Forest and the species it supports such as woodlark and nightjar is uncertain. If lowland heath is lost, it could have an impact on pollination in the NCA as heathland vegetation provides an early and late season nectar source. A spread of bracken could lead to changes in the colour and texture of the landscape. An increase in fire risk may also lead to restrictions in access to habitats such as heath during summer months. Suggested adaptation actions to address the vulnerability of heathland to the impacts of climate change include:

- Expand the area of heathland through restoration on coniferous woodland plantation sites and re-creation on improved grass or arable land, previously developed land and other engineered landforms. Target this to ensure expansion of and linkage with existing sites. Such activity would need to take account of the quality of provision, and current policy and regulation on deforestation.
- Greater monitoring for pests and diseases in case existing pests spread and novel pests arrive as a result of climate trends. Consider a notification network for land managers in relation to key pests such as heather beetle *Lochmaea suturalis* and *Phytophthera* spp, in particular to identify whether climate change is increasing pest prevalence and impact in the NCA.
- Introduce or review risk based fire management plans for lowland heath.
- Encourage use of a combination of techniques (rolling, chemical application, grazing, and cutting) to control growth of bracken which compromises slow growing heather species, and consider introducing new approaches to bracken control. Develop a significant market for bracken litter to make control methods more economically viable.
- Manage stands to have an age range of heather, to provide heterogeneity of habitat and increase resilience.
- In the longer term, consider moving species for which heathland areas have become hostile to “safer” locations. Such action would need very careful consideration, particularly in relation to designated sites, and preliminary research would be needed to identify candidate species and appropriate techniques for translocating them and helping them to become established.

Opportunities:

- Undertake research and monitoring of the heathland pollinator populations in Sherwood, to identify threats and opportunities from climate change.
- Support the pollination services provided by heathland by increasing habitat connectivity and, working at the local and small scale, by increasing the variety of micro-habitats to make space for a greater population of pollinators.

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Plate 14 Bracken at Oak Tree Heath, almost obscuring a path. Copyright Sherwood Forest Trust/Karyn Stander

Historic landscape, historic buildings and archaeological record

4.130 The assessment indicated that a variety of semi-natural and man-made features with historical and landscape character significance are highly vulnerable to the effects of climate change. Vulnerable features include:

- The historic built environment, and in particular polite architecture.
- The ornamental parkland associated with country houses in the Dukeries.
- Historic wetland areas and associated archaeology.
- The archaeological resource in erosion-prone sandy soils.

4.131 Actions that could be taken to reduce the vulnerability of country houses (polite architecture) and ornamental parkland include:

- For historic structures and buildings important to the character of Sherwood, take measures to improve resilience to predicted climate impacts such as heavy rainfall and flooding.
- Carry out additional research into the use of substitute species in parkland in response to the risk of an increase in pests and diseases and loss of trees due to increased storminess.
- In response to the risk of increased vegetation growth, increase scrub management on most fragile parkland features such as ha-has and ice-houses, and consider the same for hedgerows and boundary features.

Drying out of historic wetland areas:

- Increase research, survey and recording of archaeological and palaeo-environmental deposits, to inform and prioritise future management or recording.
- Reduce other sources of potentially damaging nutrients from agriculture and sewage treatment.

Erosion of sandy soils risk to the archaeological record:

- Throughout the NCA it is recommended that land management practices are used that preserve fragile archaeological deposits and assets, and in particular protect them from soil erosion. Possible approaches include:
  - Ensure sympathetic management, such as reversion to grazing or minimum tillage, for high priority and/or high risk historic archaeological sites on agricultural land.
  - Maintain grazing on parkland or other key sites to maintain best possible condition.
  - Consider where resource protection measures for soil and water can prevent problems caused by erosion.
  - Introduce fire protection measures for key historic assets in habitats where there is an increased fire risk due to climate change.

4.132 There remain significant gaps in our knowledge about the archaeological resource in Sherwood. Soil erosion is a particular risk to buried archaeology and portable artefacts. Other features of historic and cultural importance such as veteran trees are highly vulnerable to climate change. This set of recommendations relates to these areas:

- Increase the levels of survey and research so that the historic resource can be better understood and managed.
- Increase research on artefact scatters, which may be at particular risk of loss due to erosion themselves and may indicate as yet unknown features of risk, to inform future management.
- Record the cultural associations of named trees, and of caves and tunnels.
- Where changing climate conditions have made loss of an asset unavoidable, preservation by record is recommended.

Access and recreation

4.133 To a great extent, access and recreation assets are a man-made response to human behavioural needs for contact with the outdoors, fresh air, exercise etc. These needs can, to a large extent, be met regardless of the essential nature of the place, provided it exhibits certain qualities and characteristics (such as being easily accessible, not threatening or dangerous, not prohibitively expensive, and containing a basic set of infrastructure requirements suited to the activity). On this basis people are able to enjoy and benefit from access and recreational assets across the globe in all manner of climatic conditions - the key is to ensure that management of the assets meets the human requirement by adapting its approach to the dominant climatic conditions.

4.134 For Sherwood, which has a wide variety of assets, this means that access and recreation are likely to continue to be very important services. Some assets might change, but there is a strong capacity to adapt and so maintain recreation opportunities. For a few key assets, notably the heathland and wood pasture, and designed parkland, where the features that people are specifically there to visit are more vulnerable to climate change, a greater focus is needed on building resilience of those features to climate change so that people can continue to enjoy them into the future.

4.135 Suggested actions which may increase the adaptive capacity of recreation assets in Sherwood include:

- Ensure access management philosophy and policy remains open and adaptive to change in design, management and maintenance practice. Except where there are unique and irreplaceable assets where conservation is paramount, the general approach should be to harness change to deliver net environmental gain, for instance through the transition of heavily managed urban green spaces into more robust and naturalistic greenspaces that are suited to the prevailing climate.
- Respond to changing needs of visitors in response to climate change, for example by allowing for access at different times of day or providing increased shade in public parks.
- Where education is an important element, consider changes in education and interpretation practice to promote understanding of climate change impacts on site.
- Work with land managers to manage rights of way and permissive routes to support adaptation to climate change impacts.
- More route maintenance to keep paths open in response to increased vegetation growth during a longer growing season, increased erosion, or water-logging following storms.
- Respond to erosion risks via surface stabilisation, drainage, managing slopes, putting steps in, or re-routing vulnerable sections.
- Consider increased fire risk management in high risk areas, such as heathland, parks and conifer woodland (although woodland is not currently high risk in Sherwood), especially in areas with lots of visitors.
- Change surface drainage in urban green spaces, for example, by using Sustainable Urban Drainage Systems. There is a successful example in Sherwood Energy Village.
- Manage the health and safety implications of potential sources of harm such as algal blooms and branch fall.
- Manage the risks from potential increased incidence of swimming, boating etc, and take the opportunities to make the most of recreational benefits arising from these activities.

Strategic actions

4.136 A number of more strategic actions, which would provide an over-arching framework for delivering adaptation within the Sherwood NCA, were identified. These include:

4.137 **Monitoring:** It has been suggested that climate change may be more rapid than natural systems can easily adapt to, leading to unexpected and potentially damaging consequences. There will be a need for increased monitoring for problems affecting individual key species and habitats, arising from alien species, new pests and diseases and climatic changes. There will also be a need to be vigilant for broader risks to habitats and landscapes, for example, from fire or wind and storm damage. Such risks may have not only direct impacts on the species of features themselves, and but also public safety implications which may limit recreational access. Adaptation actions, once implemented need to be monitored for their own effectiveness, so that they can be altered if they are having unintended adverse impacts on the ability of other services or elements of landscape character to adapt to climate change. This approach also builds in flexibility.

4.138 **Increase public awareness and understanding of the potential impacts of climate change:** There is a need to invest in education and communication to ensure that the wider community understands the possible changes, and those already taking place, as Sherwood's key assets, and particularly publicly accessed areas, adapt to climate change. This makes positive change and enhancement more possible.

4.139 **Maintaining good condition and good management to build resilience:** An underlying theme in published adaptation principles for conservation managers (for example, Hopkins *et al*., 2007) is that where a habitat is maintained in good condition it is likely to be more resilient to the challenges presented by a change in climate. The same principle can also be applied to the management of some other key natural features in Sherwood – soils, water and access and recreation services, for example. Where good management practice is underway, then the challenge posed by climate change is more manageable. Removal of other environmental pressures is a key component of this.

4.140 **Connecting and buffering habitats, taking opportunities to improve access and recreation facilities and protect the historic environment and expanding woodland:** The extent to which vegetation networks exist is likely to be a factor in resilience to climate change. Adaptation principles (Hopkins 2007 and others) also support making connections between habitats. Habitat expansion was identified as a potential adaptation action for all the habitats looked at in this study and there is potential to expand habitats to create new connections and habitat networks in areas of the NCA where such connectivity does not exist or is poor. In particular, a woodland opportunity mapping study (East Midlands Landscape Partnership, 2010b) identified potential for sensitively sited new woodlands.

4.141 **Creating as much variety in habitats as possible:** Consistent with landscape character, to create heterogeneity and enhance biodiversity. This includes considering slope, aspect and altitude in habitat creation and management. Build climate change adaptation into the spatial planning agenda.

4.142 In the context of this study, this means considering how the key features of the landscape that contribute to landscape character, biodiversity and ecosystem services can be made more resilient to climate change and helped to adapt as development takes place; and also, in turn, how these elements of the landscape can be used to make it easier for human communities and individuals to adapt to climate change. This is particularly relevant when developing longer term plans for community resilience and sustainable adaptation of key infrastructure. Opportunities exist to incorporate policies at a landscape scale for multi-functional green infrastructure. Work to maintain and enhance trees and woodland can help climate regulation, which may be particularly important in the urban areas which form a quarter of the Sherwood area. Sustainable drainage systems may help address some of the impacts of climate change, while also enhancing and protecting ecosystem services such as fresh water provision and maintaining freshwater and waterside habitats.

Plate 15 Heathland regeneration along the A617 Rainworth Bypass

5 Discussion

Climate change and the vulnerability of landscape character, ecosystem services and biodiversity

5.1 The results of this study highlight that climate change poses a number of risks to the valued aspects of landscape character, ecosystem services and biodiversity in the Sherwood NCA. It appears that there are three areas of Sherwood where valued assets and services may be particularly vulnerable:

- Rivers, lakes, streams and their corridors. This is a relatively small part of Sherwood by area. Groundwater and water flow is already a much reduced resource and projected changes in rainfall patterns will make it worse. This will have impacts across habitats, access and recreation, and the historic environment in those areas.
- The ancient woodland at the heart of Sherwood and the associated heathland and grassland habitats. This central part of the NCA has value across all the natural environment assets considered here. Its key features (veteran trees, heath and grassland, the historic record, genetic resources and accessibility) are vulnerable to almost all the projected climate trends. A decline in the condition of these assets would be likely to adversely affect their cultural, inspirational and recreational value. Part of the value of this area is the cumulative impact of so many valued assets, particularly the ancient trees and associated habitats, and the services they offer for access, inspiration and study.
- The Dukeries in the northern part of the NCA. What makes this area so unusual and valuable from a historic environment perspective is that there are so many historic parks and gardens and associated buildings in such a small area, as well as features such as remnant water meadows, veteran trees and lakes. The report has already noted that the historic environment is made up of irreplaceable assets, many of which are very vulnerable to climate impacts.

5.2 Conversely, climate impacts on other aspects of Sherwood's landscape character, ecosystem services may be more subtle and indirect, such as changes in agriculture, to the appearance of conservation areas, and to geological features.

Findings of the adaptation assessment

5.3 The adaptation assessment identified a long list of adaptation actions. Many of these follow similar themes. Particularly notable were measures to prevent a decline in soil condition, measures to manage water resources, and building resilience in habitats to support adaptation over time. Also notable were a number of actions focused on specific locations, for example, actions aimed at managing the key heathland, grassland and wood pasture areas within the Sherwood NCA. We also identified a number of key strategic actions.

5.4 Actions which we think will have multiple benefits for landscape character, ecosystem services and biodiversity in Sherwood NCA include:

- Connecting and buffering valued habitats, taking opportunities to improve access and recreation facilities and protect the historic environment.
- Creating additional, sensitively sited woodland areas, which would also offer opportunities for landscape character enhancement.
- Creating as much variety in habitats as possible, consistent with landscape character, to create heterogeneity and enhance biodiversity.
- Exploring opportunities through new settlements and the regeneration of existing settlements to embrace concepts of green infrastructure and deliver 'strategic green

space' on a scale and to an extent that allows people to experience a degree of tranquillity, wild nature and the sense of 'getting away from the crowd'.

5.5 Actions which we think will be beneficial to the natural environment and reduce vulnerability to a range of pressures other than climate change include:

- Soil conservation measures.
- Water conservation, river and wetland management measures.
- Open and adaptive access policy.
- Ensuring existing valued habitats and assets are in good condition to reduce sensitivity to climate impacts.
- Programme of actions to optimise the health and resilience of veteran trees.

5.6 However, we have also identified potential conflicts between some adaptation actions. In a finite area, it will be a challenge to accommodate increases in all key habitats, as the strategic responses recommend, while also accommodating other key land uses.

5.7 In a few cases, adaptation actions designed to reduce the vulnerability of one type of asset to climate change might directly increase the vulnerability of another. For example, planting of deciduous woodland on former heathland areas could destroy the heathland seed bank. However, good practice and consultation can be used to reduce unintended problems. In the case of woodland planting, the historic environment record should be consulted before undertaking major tree planting, to ensure that significant sites are not inadvertently damaged.

5.8 In other cases, broadly beneficial actions will need to be implemented sensitively. Recent woodland opportunity mapping undertaken by the East Midlands Regional Landscape Partnership (East Midlands Landscape Partnership, 2010b) has suggested that it would be in keeping with the landscape to increase woodland cover. Such an increase is likely to be beneficial for a wide range of reasons, including increasing the carbon sequestration service provided in Sherwood, but the impacts on the historic environment, farming and other habitats would also need to be considered when deciding where to site new woodland.

5.9 Some conflicts are inherent to the adaptation response, where that response changes and arguably damages one aspect of the asset, while making it overall less vulnerable to climate change. For example, a proposed response to more intense rainfall is the installation of larger rainwater goods on traditional buildings and stately homes, to prevent damage to stone or brickwork, internal leaks and damage to furnishings, plaster and artefacts. However, such installations may mean that historically significant guttering and down-pipes have to be removed. The architecture of the building is an important part of the cultural service the building provides. Some adaptation responses to climate change might have to balance very carefully conflicting issues such as these.

5.10 Many actions can be taken now, and some are already underway. For example, on-farm water storage is already being implemented in the NCA in order to manage water resources. Country Parks in Nottinghamshire have already increased patrols against fire and are mown more frequently in response to faster summer growth (Downend, 2008). Some actions may not be needed for several years; for example fire risk is not currently a significant issue for Sherwood's oaks and heathlands but if climate trends continue it may become one at some point in the future.

5.11 Some responses require a one-off action (fitting new rainwater gutters and downpipes to historic buildings for example), but most will require continuing action over many years to allow Sherwood to adapt well to the impacts of climate trends. An example is action to address bracken growth, which is an increasing problem for heathland habitats. It is something that land managers within the NCA are tackling now, and continuing to manage bracken effectively should increase the adaptive capacity of the area. However, it is not so easy to foresee whether bracken management will, in thirty or forty years time, be such a significant issue. This highlights the importance of active adaptive management, trying out a range of new approaches and monitoring both continued environmental change and the effects of our management actions, and modifying approaches/identifying the best ones as time goes by.

Opportunities for enhancing landscape character, biodiversity and ecosystem services through adaptation

5.12 Adaptation should not just be a reactive response to try to maintain what we have in the face of growing pressures. Rather there are opportunities to use some of the adaptation actions identified here to enhance the benefits provided by Sherwood.

5.13 The four most significant opportunities for enhancing landscape character, biodiversity and ecosystem services through adaptation are in soils, water, woodlands, and spatial planning/green infrastructure:

- Adaptation measures that prevent soil erosion and promote soil health will help to enhance many other areas. Most notably, these are agriculture, biodiversity, access and the historic environment. Indirectly, the cultural services provided by Sherwood – its sense of place, and resource of historical and genetic knowledge – are also protected.
- Work to protect wetland/water areas and manage higher winter rainfall through better water storage and SUDS will support agriculture, prevent flooding, increase biodiversity and reduce pollution. However, there might be an issue around visual intrusion of reservoir type facilities.
- Adaptation options which include an increase in woodland areas could enhance the existing enclosed well-wooded landscape character, while bringing additional benefits for timber production, wildlife, wood fuel and green infrastructure (East Midlands Landscape Partnership, 2010b).
- Spatial planning could include adaptation measures with multiple benefits, such as green infrastructure in new areas of housing and to enhance those areas where there is already development.

Implementing adaptation at a range of scales

5.14 As noted in the introduction to this report, adaptation is needed at a range of spatial scales. Adaptation actions need to be considered flexibly, with consideration of specific place.

5.15 The NCA boundary coincides fairly closely with the boundary of the Sherwood sandstone outcrop, and as a result soils across Sherwood are largely acidic and sandy. This means that actions for soils and for geodiversity are likely to apply across the NCA. However, individual actions will still need to be tailored to specific sites. Soil erosion is a particular issue on steep slopes and these could be targeted for soil conservation measures such as contour based ploughing or conversion to grassland.

5.16 For rivers and streams, adaptation actions need to be planned and implemented at the catchment scale. The amount of riverine wetland in Sherwood is very small, but it is part of the Humber River Basin. Actions in the Idle and Torne catchments that influence flow and water quality will affect river flows, water quality, and landscape form and function downstream.

5.17 While measures aimed at allowing effective collection of water in the aquifer might be limited to the NCA, the aquifer is used to supply water across the Midlands. Measures to support its adaptation could therefore include work to change customer behaviour to save water over a much wider area.

Limitations of the study

5.18 This study was undertaken as part of a project to investigate how the vulnerability of the natural environment can be assessed at a landscape scale. While it is hoped that the results provide a robust set of conclusions on possible effects of climate change on the natural environment in Sherwood, we recognise a number of limitations to the methodology and results of the study, including:

- Uncertainty over the potential response of individual species to the impacts of climate change, the effects on interacting species, and consequent changes to ecological communities. This study considered the vulnerability of biodiversity at the level of broad vegetation types. Our understanding of what might happen to individual species is uncertain, thus limiting our assessment of the vulnerability of habitats. For example, this report suggests that lowland acid grassland is moderately vulnerable overall. Climate pressures are likely to result in a change in species composition to more drought tolerant species of grass and flowers, while remaining acid grassland. However, at this stage we are unable to assess the consequential impacts of this on the grassland fauna.
- Difficulty in scoring relative exposure, sensitivity and adaptive capacity (and vulnerability overall) across assets, and reliance on subjective expert judgement for the scoring. The scoring was done in several group exercises during a workshop, and aggregated and reviewed afterwards to minimise the impact of this weakness. A broad range of experts were consulted during this study and present at the workshop. Their input was supplemented by reference to published papers during the research and writing-up phases of the study. However, there is more knowledge about some of the features studied than others, and this may limit the robustness of the assessments in the report.
- The extent to which vegetation communities form coherent networks is likely to be a contributing factor to resilience/vulnerability. This lack of a spatial assessment of vegetation fragmentation is a weakness of the way that the vulnerability of biodiversity was addressed in this study. Natural England is currently conducting research to address this.
- The study was desk based, and while it involved input from many experts and stakeholders it did not involve field study, and was, rather, a qualitative assessment.

Other pressures and constraints on Sherwood NCA

5.19 In focusing on direct and indirect impacts of climate change on the assets, this report has not taken into account the future challenges for Sherwood NCA from societal and economic change. Some of those changes may themselves be indirectly influenced by climate impacts, but the linkages are complex. The cumulative impact of many factors will influence the future of Sherwood and those who live there. For example, agriculture, timber and energy crop production will be affected by a combination of climate change impacts but also short and long term economic factors such as commodity prices. Responses to climate change, naturally occurring or designed, might result in different woodland and parkland species. Different species might eventually be grown for timber if they are more resistant to disease or other climate impacts. However, there are other cultural, economic and biodiversity issues to consider when trying to manage change. These are areas where research and community engagement will both be particularly valuable.

5.20 Sherwood's landscape character, biodiversity and ecosystem services will be affected by housing growth, business and infrastructure development. This could have a positive effect on Sherwood where development results in new habitats and recreational spaces; on the other hand, development may also squeeze the space for agriculture and habitats.

5.21 Air and water pollution is another wider issue with significant potential impacts. As examples, nitrogen deposition pollutes water courses, and increased atmospheric nitrogen encourages growth of grass species at the expense of heathers.

5.22 Cultural and societal attitudes and behaviours will change over time in ways that may not be predictable. Behaviour change may have a direct or indirect impact on the character, ecosystem services and biodiversity of Sherwood. These may offer opportunities or threats to Sherwood’s adaptation to climate change.

5.23 This report does not consider how climate change mitigation activities (for example, renewable energy, changes to housing stock) might impact on the landscape character, ecosystem services and biodiversity of the NCA.

Conclusion

5.24 The study provides a systematic assessment of the valued assets and functions of the natural environment of the Sherwood National Character Area. By adopting an integrated approach to a specific location, this study and its sister studies have been able to look beyond the broad principles for adaptation for biodiversity outlined in Conserving biodiversity in a changing climate (Hopkins *et al.,* 2007) to develop more specific adaptation proposals linked to a local landscape and the wider benefits and services it delivers.

5.25 It is hoped that the findings of this study into climate change vulnerabilities and adaptation should provide a useful foundation for both further assessment of vulnerability in this and neighbouring character areas, and for the development of adaptation strategies in the Sherwood NCA. We hope the study will provide a useful resource to help inform future planning and policy development by public, voluntary and private organisations across Sherwood, and help support future partnership working, as many of the proposed adaptation measures cut across responsibilities and local authority boundaries.

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Appendix 1 Consultees

List of those responding to consultation, Autumn 2009

- Tim Dawson – Bassetlaw District Council
- Paul Evans – Defence Estates
- Kathy Wimble – Newark and Sherwood District Council
- Izi Banton – Nottinghamshire County Council
- Jason Mordan – Nottinghamshire County Council
- Peter Jarman – Nottinghamshire County Council
- Janice Bradley – Nottinghamshire Wildlife Trust
- Julia Gallagher – RSPB
- Richard Smithers – Woodland Trust

Representatives outside Natural England attending workshop 13 Jan 2010

- Katie Mills – Ashfield District Council
- Keith Ambrose – British Geological Survey
- Tony Morigi – British Geological Survey
- Professor Li Shao – De Montfort University
- Dr Kate Irvine – De Montfort University
- Nailesh Ramaiya – EMRA
- Alex Hopkinson – Climate East Midlands
- Tim Allen – English Heritage
- Andrew Heaton – Environment Agency
- Anja Nonnenmacher – Environment Agency
- Margaret Neal – Environment Agency
- Alison Millward – Alison Millward Associates
- Alex Bowness – GOEM
- Nic Wort – Greenwood Community Forest
- Neil Turner – Keeper of Geology, Nottingham City Council
- Sally Gill – Nottinghamshire County Council
- Chris Jackson – Nottinghamshire County Council
- Izi Banton – Nottinghamshire County Council
- Helen Jones – Nottinghamshire County Council
- Nick Crouch – Nottinghamshire County Council
- Karyn Stander – Sherwood Forest Trust
- Charlotte Gault – The Wildlife Trusts
- Nick Sandford – The Woodland Trust
- Nikki Williams – Atkins

Comments on various versions of draft report and at subsequent presentations also received from:

- Margaret Neal – Environment Agency
- Andy Hall – Forestry Commission

- Members of the Sherwood Habitats Strategy Group, including Janice Bradley – Nottinghamshire Wildlife Trust, Carl Cornish – RSPB, Wayne Ball – Sherwood Forest Trust, Norman Lewis, Paul Tame - NFU.

Appendix 2 Vulnerability assessment tables

Table A Summary of vulnerability assessment for geology and soils

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Sandy acid soils	Drier summers Wetter winters Intense rainfall	Very prone to erosion as a result of drought, intense rainfall and wind. Soil organisms are sensitive to drought as activity is reduced.	Environmental: as soil is lost, the speed with which it re-forms is very slow because the base-rock is very low in nutrients. Management: soil is valuable as it is rare nationally and supports high value crops. It is therefore managed.	**More vulnerable**
Quarries and pits	Widely distributed Seasonal changes in rainfall patterns Higher annual average temperature	Sensitive to repeated wetting and drying or increased erosion leading to slumping. Also limited sensitivity to vegetation growth.	Management: monitoring and adaptive management will be relatively easy to undertake in managed quarries. Environmental: sandstone is not particularly sensitive to vegetation growth.	**Moderately vulnerable**
Road, rail and canal cuttings	Widely distributed Intense rainfall Seasonal changes in rainfall patterns Higher annual average temperature	Generally tolerant to changes in climate trends but may be sensitive to high rainfall which can lead to slumping and erosion. Increased vegetation growth may be issue to limited extent.	Management: very actively managed for road/rail/canal safely so high adaptive capacity. However, socio-economic needs may have greater effect than climate change.	**Less vulnerable**

Table continued...

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Outcrops and river bluffs	Widely distributed Intense rainfall Higher annual average temperature Drier periods	Generally tolerant to changes in climate trends but sensitive to flooding which can lead to erosion. Vegetation growth. Drought periods could increase sensitivity of river bluffs and their erosion (by wind or water movement or animal/human movements).	Management: low adaptive capacity, not actively managed. Environmental: follow a natural adaptive process that may only be slightly increased as a result of climate change.	**Less vulnerable**
Caves and tunnels	Intense rainfall Wetter winters	Interior areas relatively insensitive – possible cosmetic damage due to rubbish washed in by flooding. Exterior may be vulnerable to erosion An important historic feature within Nottinghamshire.	Environmental: there are a limited number of caves likely to be at risk of flooding.	**Less vulnerable**
River meanders, periglacial features	Hotter summers Drier summers Wetter winters Intense rainfall	Process is generally insensitive to climate change although an increase in erosion rate may increase rate of processes.	Environmental: meanders follow a natural adaptive process.	**Less vulnerable**

Table B Summarises the vulnerability assessment for habitats in Sherwood NCA

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Lowland acid grassland	Drier summers Warmer winters	Sensitive to drought although associated invertebrates and bird species (woodlark and nightjar) may be more sensitive than flora. Very sensitive to bracken invasion as a result of fewer frost events.	Environmental: habitat already on drought soil so are already partially adapted to dry conditions. Management: potential to manage acid grassland if arable land comes out of production or conifers felled.	**Moderately vulnerable**
Lowland fens	Drier summers Wetter winters	Highly sensitive to drought if groundwater falls too low to support habitat. Drying out may result in shifts in community composition.	Environmental: fenland now very limited in NCA so little area for adaptation to occur. Management: re-creation ability is highly dependent on availability of appropriate quality water throughout year. Projected climate trends suggest increasing pressure on water.	**More vulnerable**
Wood pasture and parkland with ancient trees	Intense rainfall Hotter, drier summers	Highly sensitive to fire in summer. Also to drought, soil compaction and an increase in pests and diseases. Invasive plants may out-compete existing species.	Environmental: veteran trees are 500-1000 years old and demonstrated their capacity to adapt to changes in climate. However, ancient trees are already subject to multiple stresses and cumulative damage. Organisms adapted to veteran trees tend to be highly specialised with limited powers to disperse to other sites. Management: this is a highly managed and monitored resource. However, it is very difficult to re-create in human timescales. Limited cohort of replacement veteran trees available.	**More vulnerable**
Lowland heath	Hotter, drier summers Warmer winters	Sensitive to fire – particularly deep burns which can destroy seed bank. Sensitive to competition from increased bracken growth due to warmer winters and a longer growing season. Sensitive to pests and diseases.	Environmental: heathland regenerates but capacity depends on extent and nature of impact and soil conditions (nitrogen deposition). Management? Many parts of the heathland resource in Sherwood are actively managed, especially those parts forming part of designated sites or Country Parks; the management requirements to maintain lowland heath's resilience are quite significant.	**More vulnerable**

Table continued...

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Wet woodland	Drier summers Wetter winters	Highly sensitive to drought if groundwater falls too low to support habitat. Drying out may result in shifts in community composition.	Environmental? We might expect existing trees typical of wet woodland to remain for some time but for it to become progressively more difficult for new trees or areas of wet woodland to establish. Management: re-creation ability is highly dependent on availability of appropriate quality water throughout year. Projected climate trends suggest increasing pressure on water.	**More vulnerable**
Lowland mixed deciduous woodland	Intense rainfall Hotter, drier summers	Sensitive to fire in summer although less so than wood pasture as it tends to be wetter. Also to drought, soil compaction and an increase in pests and diseases. Invasive plants may out-compete existing species.	Management: this is a highly managed and monitored resource.	**Moderately vulnerable**
Deep lakes Mesotrophic lakes	Hotter, drier summers	Very sensitive to pollution, eutrophication and algal bloom. Sensitive to invasive species - cold water species are especially sensitive.	Environmental: some capacity for recovery if sufficient water quality however water pollution is currently a greater pressure than climate change. Hotter drier summers are likely to exacerbate risk of eutrophication when combined with pollution. Management: invasive species are very hard to remove. Improvements in water quality through the Water Framework Directive (WFD) may increase adaptive capacity. Prevention of invasion is the primary management. Tree shading may be used to keep water cooler.	**More vulnerable**
Rivers and streams	Hotter, drier summers	Very sensitive to pollution, eutrophication and algal bloom. Sensitive to invasive species - cold water species are especially sensitive.	Environmental: already at risk of drying up due to low water table. Water pollution currently a greater threat to habitat than climate change. The risk of eutropnication may be greater if hotter drier summers are combined with pollution Greater capacity for recovery in right conditions than deep lakes. Management: it may be possible to adjust abstraction and do works to improve aquifer recharge and groundwater supplies.	**More vulnerable**

Table C Vulnerability of historic environment assets

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Below ground historic assets	Hotter, drier summers Wetter winters	Sensitive to drying out and erosion of soil where waterlogging has preserved deposits anaerobically. This is a particular issue where peaty deposits remain, for example, River Maun. Sensitive to changes in soil chemistry and erosion caused by wetter conditions and flooding.	Environmental: each asset is a unique, non-renewable record. Extent of sensitivity is different for each asset but most have low tolerance of change before damage occurs. Depends on soil type. Management: little capacity for management. Once damaged or destroyed, assets cannot be replaced.	**More vulnerable**
Above-ground assets - earthworks	Hotter, drier summers Wetter winters	Sensitive to drying out and erosion of soils. Also sensitive to fire. Sensitive to poaching damage.	Environmental: sensitivity to poaching increased in areas of pig farming. Management: areas left as managed grassland may adapt well and most earthworks are on grazed sites. Once damaged, assets cannot be replaced.	**Moderately vulnerable**
Parkland	Hotter, drier summers Wetter winters	Native beech is sensitive to hot, dry conditions. Also sensitive to storm damage. Parkland trees are highly sensitive to pests and diseases. Increased visitor numbers in hot weather may add to local pressures.	Management: these are intensively managed sites so there is capacity for intervention to support adaptation. However, a lot of their value is in the particular design, form of trees and layout.	**More vulnerable**
Traditional field boundaries and field patterns	Hotter, drier summers	Relatively insensitive to climate change although hedgerows may be sensitive to drought. Earthworks may be sensitive to erosion.	Management: regulatory framework, good practice and management via agri-environment schemes leads to relatively good adaptive capacity.	**Less vulnerable**

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Traditional buildings and structures	Hotter, drier summers Wetter winters Intense rainfall	Sensitive to cycles of wetting and drying. Sensitive to flooding and damage caused by intense rainfall. Also sensitive to pests and fungal infections.	Environmental: age, fragility of materials and pre-existing damage affects adaptive capacity. Management: there are potential management techniques but they may have significant adverse impact on aesthetics.	**Moderately vulnerable**
Ancient or veteran trees (particularly those with cultural connections)	Hotter, drier summers Intense rainfall Wetter winters	Highly sensitive to drought, pests and diseases and wind blow.	Environmental: adaptive capacity limited by age. Trees typically already subject to multiple pressures. Management: there may be greater capacity to help veteran trees to adapt if they are considered to be of ‘ancient’ status.	**More vulnerable**
Subterranean archaeological/geological assets (particularly caves and tunnels)	Wetter winters Intense rainfall	Sensitive to flooding and alterations in humidity and temperature. This can lead to algal growth.	Environmental: the interior of caves are generally very stable environments. Very few caves in the NCA at risk of flooding.	**Less vulnerable**
Portable artefacts	Hotter, drier summers Wetter winters	Sensitive to changes in soil chemistry and drying out of anaerobic deposits.	Environmental: depends on soil types and condition of individual assets.	**Moderately vulnerable**
Historic wetlands, including water meadows	Hotter, drier summers	Sensitive to drying out and loss of evidence preserved in anaerobic conditions.	Environmental: low groundwater levels limits adaptive capacity Earthwork elements may have higher adaptive capacity.	**More vulnerable**

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Industrial and military remains	Hotter, drier summers Wetter winters Intense rainfall	Sensitive to cycles of wetting and drying. Sensitive to flooding and damage caused by intense rainfall. Buildings sensitive to pests and fungal infections.	Environmental: generally tend to be Victorian with robust features. Age, fragility of materials and pre-existing damage affects adaptive capacity.	**Less vulnerable**
Polite architecture / buildings	Hotter, drier summers Wetter winters Intense rainfall	Sensitive to cycles of wetting and drying. Sensitive to flooding and damage caused by intense rainfall. Buildings sensitive to pests and fungal infections.	Environmental: age, fragility of materials and pre-existing damage affects adaptive capacity. Management: there are potential management techniques but they may have significant adverse impact on aesthetics.	**More vulnerable**
Conservation areas	Hotter, drier summers Wetter winters Intense rainfall	Buildings sensitive to cycles of wetting and drying. Sensitive to flooding and damage caused by intense rainfall. Buildings sensitive to pests and fungal infections.	Environmental: age, fragility of materials and pre-existing damage affects adaptive capacity. Management: there are potential management techniques but they may have significant adverse impact on aesthetics. Introduction of SUDs may change the look of a conservation area (but many non-climate related factors do this too).	**More vulnerable**

Table D Vulnerability of access and recreation assets

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Public rights of way network	Hotter, drier summers Wetter winters Higher annual average temperatures	Sensitive erosion during drought and flooding. Sensitive to becoming obscured by vegetation. Potential for changes in demand and different usage patterns.	Environmental: depends on soil type, footpaths on sandy soil are most sensitive to erosion. Condition of footpath is factor in usage. Management: diverse nature of footpaths, bridleways etc. may reduce vulnerability but rights of way network may not offer many alternative routes.	**Moderately vulnerable**
Urban Greenspace	Hotter, drier summers Wetter winters Intense rainfall Higher annual average temperature	Sensitive to increased use and fire risk during hotter summers. Grassed areas may dry out. Also sensitive to waterlogging and surfaces becoming muddy in wet winters.	Environmental: depends on soil type. Management: highly modified and a managed resource, adaptation can be built in to management. May be an increase in management requirements. Paths are often well surfaced so able to recover from shocks or cumulative impacts.	**Less vulnerable**
Country Parks, LNRs, NNRs	Hotter, drier summers Wetter winters Intense rainfall Higher annual average temperature	Variable – see habitats section. For LNRs and NNRs sensitivity depends on the specific features of interest for which designation made.	Management: areas all actively managed so likely to be in good condition and systems in place to take recovery action. Environmental: if key features for which people visit site are lost or significantly damaged due to climate change (for example, loss of veteran trees) possible reduction in recreational value of specific site.	**More vulnerable**
Open access land – heaths commons and greens	Hotter, drier summers Wetter winters	Sensitive to erosion caused by drought and flooding. Also sensitive to fire. See also habitats section.	Management: adaptive capacity may depend on whether access land is habitat based (for example, heath) or legally/culturally based (commons).	**Moderately vulnerable**

Table continued...

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Accessible woodland	Hotter, drier summers Wetter winters	Sensitive to health and safety concerns about fire, falling branches, pests etc. Habitat sensitive to drought (see also habitats section).	Management: asset is generally Forestry Commission managed woodland. Depends on proximity to population, woodland type and intensity of usage but significant loss of accessible areas unlikely.	**Moderately vulnerable**
Registered parks and gardens; accessible private estate land	Hotter, drier summers Wetter winters Intense rainfall Higher annual average temperature	Sensitive to increased use and fire risk during hotter summers. Grassed areas may dry out. Also sensitive to waterlogging and surfaces becoming muddy in wet winters.	Management: potentially high adaptive capacity as areas is managed although historic assets would be hard and in cases impossible to replace, which may in long term reduce recreational value of visit, when the visit is to look at particular cultural elements.	**Less vulnerable**
Water bodies	Hotter, drier summers	Sensitive to drying out in summer as well as algal blooms and bank erosion. Use for angling is sensitive to changes in species abundance and composition. Sensitive to increase visitor use.	Environmental: smaller water bodies may be more prone to drying out. Management: potential to modify management and perhaps increase opportunities for open water swimming, boating etc.	**More vulnerable**

Table E Vulnerability assessment for natural resource assets

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Aquifer	Drier summers Wetter winters Extreme dry/wet events	Sensitive to drying out in summer when demand is highest. Sensitive to a shorter/ineffective re-charge period. Duration and frequency of rainfall is most important for aquifer recharge.	Environmental: sandstone may store water less effectively during intense rainfall periods. Water quality is already below that required by WFD. Aquifer is already water stressed.	**More vulnerable**
Surface water sources	Hotter, drier summers Wetter winters	Sensitive to pollution from run-off and silting during flood events and concentration of pollutants (low dilution capacity) during low water levels. Sensitive to drying out in summer.	Environmental: most surface water sources not at standard required by WFD. May have some adaptive capacity where sufficient flow.	**More vulnerable**
Pollinators	Hotter, drier summers Warmer, wetter winters	Pollinators will be sensitive to changes in phenology, for example, changes in wild-flower lifecycles. Also sensitive to changes in agricultural systems.	Environmental: generalist pollinators will have greater adaptive capacity than specialist pollinators. Species isolated in a habitat will have lower capacity.	**More vulnerable**
Energy crops (particularly short rotation coppice (SRC))	Intense rainfall events Warmer, wetter winters Hotter, drier summers	SRC is sensitive to low rainfall – it requires >600mm rainfall annually. Drier summers may also damage any late SRC plantings. Also sensitive to prolonged winter water-logging. Sensitive to abrasion from soil erosion and high winds, particularly young SRC growth. Sensitive to pests including willow beetle, rust, poplar beetle, aphids.	Environmental: current rainfall is only just sufficient to sustain SRC. Management: highly managed resource. There are alternative energy crops and short rotation forestry options.	**Less vulnerable**

Table continued...

Asset	Potential exposure	Sensitivity	Adaptive capacity	Potential vulnerability
Agriculture: crops, pigs and poultry	Hotter, drier summers Warmer wetter winters	Crops sensitive to drought, increases in pests and diseases, heat stress in stock. Fields sensitive to erosion in wet periods and nutrient loss in soils; increased need for shelter for stock in wet weather and risk of poaching of ground.	Management: a highly managed resource with alternative crops and stock management methods an option. Some climate impacts may be beneficial.	**Moderately vulnerable**
Timber plantations	Hotter, drier summers Warmer, wetter winters Intense rainfall events	Sensitive to wind blow, drought and waterlogging. Particularly sensitive to pests and diseases (red band needle blight affecting Corsican pine). Potentially sensitive to fire risk.	Management: highly managed resource; alternative timber crops an option.	**Less vulnerable**

Appendix 3 Implications of vulnerability assessment for landscape character and ecosystem services – element by element analysis

In this appendix the implications of the vulnerability of specific assets on landscape character, ecosystem services and biodiversity are identified. The vulnerability assessments have been carried out at the scale of specific assets which contribute to landscape character, ecosystem services and biodiversity. In this appendix we show our analysis of the cumulative effects of the vulnerabilities identified on landscape characteristics, ecosystem services and biodiversity.

Implications for landscape character of Sherwood NCA

Rolling landform and sandy soils

This aspect of Sherwood's character should not be significantly changed by climate trends as geomorphologic processes will continue and Sherwood's underlying geology is not anticipated to be vulnerable. However, sandy soils are likely to be increasingly vulnerable to erosion, and this is likely to be visible in the landscape.

Large amount of woodland, with frequent views of wooded skylines

Overall this characteristic of the landscape is likely to change slowly. Woodland assets will remain a key part of the landscape, even if the species composition may change. Earlier greening may change the wooded appearance of the landscape.

However, evidence suggests that some types of woodland may be more vulnerable to climate change than others. Wind blow, increased drought and associated fire risk, novel pests and diseases are likely to be a challenge to all trees, but particularly to the veteran oak trees that are the core of Sherwood Forest. Regular monitoring and management of these trees is under way, and would need to continue.

Locally conspicuous sandstone quarries

Demand for sandstone extraction is more likely than climate change to affect the number and extent of quarries in the landscape.

Extensive enclosed arable farmlands with rectilinear field patterns divided by low, treeless hedges

The field pattern itself is most likely to change due to economic factors rather than climate change. Larger fields tend to be more economical to farm with large machinery or through contract farming, which is, in the short term at least, an option increasingly used.

Climate change might result in different crops being planted and, should tall crops such as maize or SRC which are higher than the surrounding hedges be used more widely, that would change the impression that the fields currently give. Hedges are likely to be increasingly vulnerable to drought and to pests and diseases.

Strong heathland character

Change in this habitat could be significant in time but it is not possible to predict whether changes will be beneficial or detrimental to the landscape character. Low nutrient soil which might result from increased soil damage would favour growth of heathland plants. Similarly, should farming move away from lower fertility soils there will be scope for an increased area of heathland and lowland acid grassland. On the other hand, increased growth of scrub and bracken resulting from predicted longer growing seasons may alter the habitat from heathland to scrub without management.

Fire may be an increasing risk during drought periods. The extent and ferocity of fire would be a crucial factor in how easily the heathland would recover.

A move away from pine to broad-leaved plantations for commercial forestry as a result of climate trends may also reduce the area of heathland in the landscape. The heathland seed bank survives well in commercial pine plantations, and regenerates when pine is felled, but typically, after a few years of broad-leaved woodland, the soil no longer supports the heathland habitat.

Country houses set in ornamental parkland and estate villages

Externally visible changes to the appearance of the houses may result from the installation of larger rainwater goods. Damage to or loss of specimen trees in designed parkland may occur and would alter the appearance of the landscape. These trees may be of particular importance because they are part of a designed landscape. Programmes of managed replacement can encounter difficulties due to the aesthetic difference between the species likely to thrive and those intended when the area was designed. This could have an adverse impact on the historic and cultural quality of the parkland.

Narrow man-made lakes, meandering river channels, flood meadows and in places fringing alder, willow and scrub

Drought, low groundwater levels and intense rainfall all have the potential to damage lakeside habitat and riverside trees and reduce the area of open water in the landscape. Increased drought is likely to result in rivers which already have a tendency to dry up completely in areas during summer will do so more frequently. Such areas are then vulnerable to scrub invasion. Consequent habitat change, if permanent, would alter the NCAs character.

Mining heritage

This characteristic is unlikely to be significantly affected by climate change.

Vernacular buildings of handmade red brick and of sandstone

Damage due to severe weather may result in more ruinous buildings in the landscape. Some original features may be obscured by new external rainwater goods or other modifications to make the building more resilient to climate change, changing the appearance of traditional buildings. Increased use of farm buildings by stock in wetter winters may also increase damage or result in change to their fabric.

Locally distinctive rural settlement patterns

Whilst the appearance of some buildings or villages may be affected by climate change mitigation measures it is likely that housing growth and changes in rural industry will affect rural settlement patterns more than climate change.

Significant urban and urban fringe elements

Growth in housing and changes in industry are more likely to affect this characteristic than climate change. Some historic environment elements may be obscured by changes designed to protect buildings from the impact of change, such as new rainwater goods, but that needs to be balanced against the benefits that comes from having such protective measures in place. The impact of renewables and home carbon efficiency measures such as solar panels and double-glazing on the urban historic landscape is beyond the remit of this study. However, they are perceived as likely to have a profound effect on the built historic environment (Council for British Archaeology *et al.*, 2010).

Implications for ecosystem services of Sherwood NCA

Mixed arable farming, pigs and poultry

It is hard to separate climate from economic and social trends in considering the future of farming in Sherwood. Introduction of new crops, intensification of agriculture in response to economic demand or better growing conditions, management changes in response to changing input prices and development of new techniques or abandonment of land to waste if it becomes uneconomic to farm are all possible futures. Temperature changes will affect timing of planting and harvesting of crops and quality. Of the typical crops of Sherwood, carrots could benefit from higher temperatures. Potatoes may be able to be left in the ground for longer if frosts begin later and yields may improve. However pests and diseases such as potato blight may affect crops more frequently. Good water management, soil management and husbandry will continue to be crucial.

Fresh water

Water resources are likely to become increasingly scarce if the trend for hotter drier summers and warmer wetter winters with more intense rainfall events throughout the year occur. It will become more difficult for the aquifer to recharge, whilst river flows and groundwater levels will decrease. This pressure on water supply is likely to be combined with higher demand for water in summer, increasing pressure on water resource. This pressure is likely to be exacerbated by increased demand for irrigation from groundwater and surface water sources.

Timber

The Forestry Commission suggests that the composition of woodland managed for timber may change over time, however timber production is likely to continue. Timber production may be affected by new diseases which could be a significant issue for monoculture timber crops. Disease could result in the felling of relatively large areas of woodland, making a significant difference to the appearance of the landscape as alternative species are planted in their place. Red Band Needle Blight, a disease of conifers, seems to be increasing in the UK's managed forests possibly as a result of changing climatic conditions. It affects a limited number of species, particularly Corsican Pine.

Biomass and renewable energy production

SRC may be adversely affected by increased drought. However, Short Rotation Forestry planting for wood-fuel production is an area of increasing interest. Wind energy production does not appear vulnerable to climate change impacts.

Minerals – coal and sandstone

This service is unlikely to be significantly affected by climate change.

Soil formation

Soils in the NCA are likely to be subject to increased erosion and wind blow. Soils are fundamental to habitats and to other services such as farming, carbon storage and timber production as well as the preservation of many historic environment assets. Our assessment suggests that all these services will be affected by damage to soils due to climate change.

Carbon storage

The carbon storage potential of soils and biomass is likely to be decreased if they are not maintained in a healthy condition. This report suggests that climate trends will tend to put soils and woodland in Sherwood under increased stress, and that carbon would be increasingly lost from the area, if remedial action is not taken.

Climate regulation

Trees and water bodies both a role in climate regulation and will continue to do so. The role of trees and waterbodies could become more important and maintaining them in a healthy state will become more critical too. We have noted that individual trees may be more at risk from pest, disease and wind-blow, but that some species will be more adaptive to climate change. We have also identified that Sherwood water bodies will be highly vulnerable to climate impacts.

Flood alleviation

It is likely that climate change will result in more intense rainfall and increased storminess, increasing the likelihood of flash flooding, despite the relatively free-draining soils of the area. This will increase the importance of this service and the assets which contribute to it.

Water quality

Water quality is likely to be affected by both drier summers and wetter winters. Drier summers lead to low water levels and the concentration of pollutants whereas flooding can introduce silt and contaminants to water bodies. Increased run-off due to intense rainfall is likely to result in nitrate pollution.

Pollination

In Sherwood, the relative lack of variety of cropping is likely to make the pollination service more vulnerable to changes. Lowland heath is identified as highly vulnerable to climate change and as heath provides a key early and late season nectar source, this may be particularly significant. Gardens may be a key nectar source in some areas, and climate change impacts on garden nectar source availability have not been considered in this report. We feel that more detailed research in this area is needed.

Sense of place, aesthetic beauty, culture

It is difficult to evaluate the effects of climate change on these services, which are dependent on human perception, experience and knowledge systems. There is potential for climate change trends to enhance or damage the cultural services that people receive from Sherwood. Possibly most harmful to current perceptions of Sherwood would be damage to the assets most associated with Robin Hood: some of the historic buildings, the lowland heath, the wood pasture and the ancient oaks, and other places with strong legendary links. We have identified that the historic environment and wood pasture appear to be highly vulnerable to climate change.

Conversely, warmer weather might enable people to experience and enjoy the landscape aesthetic qualities more frequently, and landscape change within Sherwood may enhance its visual and perceived attractiveness.

Access and recreation

To a great extent access and recreation assets are a man made response to human behavioural needs for contact with the outdoors, fresh air, exercise etc. These needs can to a large extent be met regardless of the essential nature of the asset, provided it exhibits certain qualities and characteristics (such as being easily accessible, not threatening or dangerous, not prohibitively expensive, and containing a basic set of infrastructure requirements suited to the activity). On this basis people are able to enjoy and benefit from access and recreational assets across the globe in all manner of climatic conditions - the key is to ensure that management of the assets meets the human requirement by adapting its approach to the dominant climatic conditions.

For Sherwood, which has a wide variety of assets, this means that access and recreation are likely to continue to be a very important service; some assets might change, but there is a strong capacity to adapt.

Appendix 4 Integrated response screening and identification of win-win, 'low regret' and no regret opportunities

Table F Integrated response screening and identification of win-win, 'low regret' and no regret opportunities

Adaptation options, shown by area identified	**Win-win**	**Low regrets**	**No regrets**	**Landscape character**	**Natural resources**	**Geology & soils**	**Habitats**	**Historic environment**	**Access & recreation**
Sandy, acid soils									
Increase size of small woods in intensive agricultural areas to act as wind breaks and prevent soil drift and potentially erosion.		x		x	x	x	x		
Promote good hedgerow management, and create shelterbelts and other field boundary features that will reduce soil loss.	x			x	x	x	x		
Consider changing land use (for example, from arable to grass) where the risk of soil erosion is high and soils are being lost (typically on steeper or long unbroken slopes.			x	x	x	x	x	x	x
On pasture, ensure good vegetation cover and avoid over-grazing and trampling, or damage by mechanised activities.			x		x	x	x	x	
In the longer term, switch to crops that are less reliant on irrigation and, more generally, to crops which respond well to new climatic conditions.		x			x	x			

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Adopt soil moisture conservation measures, possibly through environmental farming schemes and management plans for designated sites.		x		x	x	x	x	x	
Enhance levels of soil organic matter.			x		x	x	x	x	
Maintain good soil structural condition and avoid soil compaction or poaching which will restrict rooting.			x	x	x	x	x	x	x
Use a minimum tillage approach to reduce loss and erosion.			x	x	x	x	x	x	
Put buffer strips in place.			x	x	x	x	x	x	
Take measures to keep soil in situ when ploughing, for example, contour ploughing on slopes.			x	x	x	x		x	x
On cultivated land consider wind breaks, nurse crops or straw planting to minimise wind erosion.			x	x	x	x		x	
Water resources									
Promote water efficiency in developments and by consumers across the region, thus reducing pressure on the Sherwood aquifer.			x		x		x		
Adopt water-efficient irrigation techniques.			x		x	x			
Relieve soil compaction caused by inappropriate land management practices to increase water infiltration.			x	x	x	x	x	x	
Increase on-farm water storage to collect heavier winter rainfall and reduce the need for abstraction from the aquifer and river sources for crop irrigation purposes during dry periods.			x	x	x	x	x		
Increase water retention through the catchment by increasing tree cover and reducing the extent of bare ground and hard surfaces.	x			x		x	x	x	

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Employ land management practices and consider the introduction of different forms of land cover to reduce pollution which has particular impact on water courses during times of low flow. Examples given are buffer strips and energy crop planting near water courses.	x				x	x	x		
Increase resilience of deep lake ecosystems and wetland areas by reducing pressures on them from nutrients, sediments and non-native species.			x	x	x	x	x	x	x
Enhance structural diversity of lake habitats.			x	x	x	x	x	x	x
Realise opportunities for wet woodland creation along streams and rivers in agricultural landscapes to increase habitat and reduce pollution run-off.	x			x	x	x	x		
Establish storm-water storage capacity for urban areas and agricultural areas, in particular along Idle and Torne, using these as opportunities to recreate wet woodland and fen.	x			x	x		x	x	
Encourage use of Sustainable Urban Drainage Systems.	x				x	x	x		
Woodlands									
Risk based fire management plans for wood pasture and particularly high value assets such as veteran oaks.			x	x	x		x	x	
Maintain grass heath vegetation around trees to maintain moisture in soil.			x	x		x	x		
Use lightning conductors and non-intrusive bracing systems to reduce risks to ancient trees from increased storm threat.	x			x			x	x	
Consider increased stabilisation management of ancient trees to reduce risk of wind-blow.	x			x			x	x	
Ensure that competing trees are removed from around ancient trees.			x	x			x	x	
Develop further the native tree nursery at Sherwood Pines to ensure survival of trees of local provenance.			x	x			x	x	

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Improve management around existing known veteran trees, ensuring that there is no cultivation, browsing or barking of trees, and reduce fertilisation and pesticide use in the area. Alternatively, consider aerating or make use of mulch around key ancient trees, taking account of invertebrate interest.			x	x	x		x	x	
Identify any further unknown veteran trees in the landscape and log them on a shared data base to ensure they are maintained.			x	x	x		x	x	
Plan to support the next generation of ancient trees by maintaining the health of mature oak trees.			x	x	x		x	x	
Allow fallen trees and decaying wood to remain in situ where practicable to maintain habitat for key invertebrates.			x	x			x	x	x
Registering seed stands and recording them on a local origin database.	x			x	x		x		
Avoid soil compaction or poaching around trees and woodland caused by inappropriate land management, which will restrict rooting.			x	x			x		
Increase vigilance for pests and diseases in all woodland.			x	x	x		x		
Plant tree species that are likely to tolerate predicted future climates. This will require consideration of how, where and whether trees could be replaced with more climate change tolerant native or introduced species of trees (Ray, Morison and Broadmeadow, 2010).	x			x	x		x		x
Consider greater use of mixed planting, particularly for timber crops, as single species plantations are more at risk of total crop loss due to pests and diseases (Read, 2009).		x		x	x		x		
Promote the use of in-field and boundary trees, parks and wood pasture as potential shade.	x			x			x		x
Bring woodland areas into management for their role as carbon sinks and in flood alleviation. In particular, consideration should be given to creating wet woodlands along rivers as part of flood alleviation programmes, as wet woodland is an increasingly small but characteristic element of Sherwood's landscape, and a BAP habitat.	x			x	x	x	x		

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Increase connectivity of individual woodland stands.			x	x			x		
Look for opportunities to use Short Rotation Forestry in Sherwood NCA.			x	x	x				
Maintain the existing urban treescape and plant new urban trees to increase shade.			x	x			x		x
Increase the use of natural vegetation in built schemes and landscaping (for example, green roofs, trees and shrubs) to increase shading and to absorb heat.	x			x			x		x
Heathland									
Expand the area of heathland through restoration on coniferous woodland plantation sites and re-creation on improved grass or arable land, previously developed land and other engineered landforms. Target this to ensure expansion of and linkage with existing sites. Such activity would need to take account of the quality of provision, and current policy and regulation on deforestation.			x	x	x		x	x	x
Greater monitoring for pests and diseases in case existing pests spread and novel pests arrive as a result of climate trends. Consider a notification network for land managers in relation to key pests such as heather beetle and *Phytophthera* spp, in particular to identify whether climate change is increasing pest prevalence and impact in the NCA.			x	x	x		x		
Introduce or review risk based fire management plans for lowland heath.		x		x			x		
Encourage use of a combination of techniques (rolling, chemical application, grazing, and cutting) to control growth of bracken which compromises slow growing heather species, and consider introducing new approaches to bracken control. Develop a significant market for bracken litter to make control methods more economically viable.			x	x			x		x
Manage stands to have an age range of heather, to provide heterogeneity of habitat and increase resilience.			x	x			x		

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
In the longer term, consider moving species for which heathland areas have become hostile to “safer” locations. Such action would need very careful consideration, particularly in relation to designated sites, and preliminary research would be needed to identify candidate species and appropriate techniques for translocating them and helping them to become established.		x					x		
Undertake research and monitoring of the heathland pollinator populations in Sherwood, to identify threats and opportunities from climate change.	x				x		x		
Support the pollination services provided by heathland by increasing habitat connectivity and, working at the local and small scale, by increasing the variety of micro-habitats to make space for a greater of pollinators.			x	x	x		x		x
Historic landscape, historic buildings and archaeological record.									
For historic structures and buildings important to the character of Sherwood, take measures to improve resilience to predicted climate impacts such as heavy rainfall and flooding.			x	x				x	
Carry out additional research into the use of substitute species in parkland in response to the risk of an increase in pests and diseases and loss of trees due to increased storminess.	x			x				x	x
In response to the risk of increased vegetation growth, increase scrub management on most fragile parkland features such as ha-has and ice-houses, and consider the same for hedgerows and boundary features.	x			x			x	x	x
In historic wetland areas increase research, survey and recording of archaeological and palaeo-environmental deposits, to inform and prioritise future management or recording.	x			x				x	x
In historic wetland areas reduce other sources of potentially damaging nutrients from agriculture and sewage treatment.			x	x	x	x	x	x	
For erosion of sandy soils where there is a risk to the archaeological record. Ensure sympathetic management, such as reversion to grazing or minimum tillage, for high priority and/or high risk historic archaeological sites on agricultural land.			x	x	x	x	x	x	

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Maintain grazing on parkland or other key sites to maintain best possible condition.			x	x		x		x	
Consider where resource protection measures for soil and water can prevent problems caused by erosion.			x	x		x	x	x	
Introduce fire protection measures for key historic assets in habitats where there is an increased fire risk due to climate change.	x			x			x	x	
Increase the levels of survey and research so that the historic resource can be better understood and managed.			x	x				x	
Increase research on artefact scatters, which may be at particular risk of loss due to erosion themselves and may indicate as yet unknown features of risk, to inform future management.		x						x	
Record the cultural associations of named trees, and of caves and tunnels.		x		x				x	
Where changing climate conditions have made loss of an asset unavoidable, preservation by record is recommended.		x						x	
Access and recreation									
Ensure access management philosophy and policy remains open and adaptive to change in design, management and maintenance practice. Except where there are unique and irreplaceable assets where conservation is paramount, the general approach should be to harness change to deliver net environmental gain, for instance through the transition of heavily managed urban green spaces into more robust and naturalistic greenspaces that are suited to the prevailing climate.			x	x			x		x
Respond to changing needs of visitors in response to climate change, for example by allowing for access at different times of day or providing increased shade in public parks.	x			x					x
Where education is an important element, consider changes in education and interpretation practice to promote understanding of climate change impacts on site.		x							x

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Work with land managers to manage rights of way and permissive routes to support adaptation to climate change impacts.			x			x	x		x
More route maintenance to keep paths open in response to increased vegetation growth during a longer growing season, increased erosion, or waterlogging following storms.			x			x	x		x
Respond to erosion risks via surface stabilisation, drainage, managing slopes, putting steps in, or rerouting vulnerable sections.			x			x	x		x
Consider increased fire risk management in high risk areas, such as heathland, parks and conifer woodland (although woodland is not currently high risk in Sherwood), especially in areas with lots of visitors.	x			x	x	x	x	x	x
Change surface drainage in urban green spaces, for example, by using SUDS.	x						x		x
Manage the health and safety implications of potential sources of harm such as algal blooms and branch fall.	x			x			x		x
Manage the risks from potential increased incidence of swimming, boating etc, and take the opportunities to make the most of recreational benefits arising from these activities.		x							x
Strategic actions									
Increased monitoring for climate-change related problems affecting individual key species and habitats, and vigilance in relation to broader risks to habitats and landscapes, for example from fire or wind and storm damage.	+			+	+		+	+	+
Maintain good condition and good management of habitats and assets to build resilience.			+	+	+	+	+	+	+
Increase public awareness and understanding of the potential impacts of climate change.			x	x	x		x	x	x
Connect and buffer habitats, taking opportunities to improve access and recreation facilities and protect the historic environment and expanding woodland.			x	x	x	x	x	x	x

Table continued…

Adaptation options, shown by area identified	Win-win	Low regrets	No regrets	Landscape character	Natural resources	Geology & soils	Habitats	Historic environment	Access & recreation
Create as much variety in habitats as possible, consistent with landscape character, to create heterogeneity and enhance biodiversity.			x	x	x	x	x		
Build climate change adaptation into the spatial planning agenda.	x			x	x	x	x	x	x

Natural England works for people, places and nature to conserve and enhance biodiversity, landscapes and wildlife in rural, urban, coastal and marine areas.

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