Natural England Research Report NERR050

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

www.naturalengland.org.uk

Natural England Research Report NERR050

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

Richard Wilson[1], Colin Holm[1], Ruth Bull[1], Nicholas A. Macgregor[1], Nikki Van Dijk[2], Geoff Darch[2] and Andy Neale[1]

[1]Natural England

[2]Atkins

Published on 16 August 2013

ISBN 978-1-78354-028-0

Project details

This work was carried out in order to consider the vulnerability of the natural environment to climate change in the Humberhead Levels Character Area. It was undertaken by: Richard Wilson, Colin Holm, Ruth Bull, Nicholas A. Macgregor and Andy Neale from Natural England, and Nikki Van Dijk and Geoff Darch from Atkins.

This report should be cited as:

WILSON, R., HOLM, C., BULL, R., MACGREGOR, N.A., VAN DIJK, N., DARCH, G. & NEALE, A. 2013. Assessing the potential consequences of climate change for England's landscapes: Humberhead Levels. *Natural England Research Reports, Number 050*.

Project manager

Andy Neale
Block B Government Buildings,
Whittington Road,
Worcester,
WR5 2LQ
Tel: 0300 060 0403
andy.neale@naturalengland.org.uk

Acknowledgements

The authors would like to thank the following for their contribution to the production of this report:

1) Colleagues in Natural England.
2) The Humberhead Levels Partnership members who participated in February 2010 workshop.
3) Representatives of organisations who contributed to the report and particularly participants who attended the workshop in January 2010.

- Country Land and Business Association
- Doncaster Council
- English Heritage
- Environment Agency
- Isle of Axholme Drainage Board[1]
- National Farmers Union
- Natural England
- North Lincolnshire Council
- RSPB
- Selby District Council
- Woodland Trust
- Yorkshire Wildlife Trust

[1] Now known as Isle of Axholme and North Nottinghamshire Water Level Management Board

Summary

This study, which was undertaken in 2010, considered the vulnerability of the natural environment to climate change in the Humberhead Levels National Character Area. It was one of a series of studies carried out by Natural England to explore the potential consequences of climate change for the natural environment across England and to consider appropriate adaptation options. The Humberhead Levels is a broad floodplain at the head of the Humber Estuary; a largely agricultural area containing a number of important rivers flowing into the estuary and wetlands associated with them, and nationally important areas of lowland peat bog.

The vulnerability of the natural environment in the Humberhead Levels NCA was assessed by considering how exposed it is 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 was based on the best available scientific knowledge of how climate change might affect the natural environment and discussions with local experts. The assessment considered both landscape assets (biodiversity, heritage, soils and geology) and its ecosystem service functions.

The study highlighted in particular that the following areas or aspects of the natural environment in the Humberhead Levels could be highly vulnerable to climate change:

- Agricultural land and the character of the broad floodplain could be affected by changes in land use in response to climate change. Such changes are hard to predict but in a predominantly agricultural area such as the Humberhead Levels they are likely to have a more significant impact than the direct effects of climate change itself.
- Rivers and wetlands could be affected by changes in seasonal water flows and by the management that is taken in response, with consequences (both negative and positive) for a range of ecosystems and the species they support. There is likely to be a greater need to use floodplains and temporary wetlands to store floodwater and alleviate flooding.
- Estuarine wetlands in the east of the Humberhead Levels near the upper end of the Humber estuary could be affected by sea level rise and erosion and 'squeezed' against flood defences. This would result in loss of important wildlife habitat and reduction in the flood alleviation service these wetland areas can provide. Historic features near the estuary could also be lost. However, there could be opportunities to use managed realignment of the coast of the estuary as a flood defence strategy that would provide a range of benefits for both people and wildlife.
- The important lowland peatlands in the area are vulnerable to drying out and fire as a result of drier summers and waterlogging in winter. Consequences could include loss of biodiversity, increases in carbon dioxide emissions, and damage to important records of past archaeological and environmental change.
- Changes in climate could change both visitor numbers and seasonal patterns of recreation and put pressure on recreation facilities, presenting both opportunities and challenges.

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

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 Humberhead Levels. 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*., 2008; 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 in England (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, summarising these 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 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 and for that reason were used in this set of studies. Ranging in size from 1,122 ha[2] 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 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[3] – a large city, but with extensive urban green space, dominated by the influence of the river Thames.
- South Downs National Park[4], 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.

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

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

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

- North Kent – a distinctively open and atmospheric landscape dominated by industrial heritage and extensive areas of grazing marsh and intertidal habitats which support a large and varied bird population.
- Lancashire and Amounderness 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 13 studies completed in the two phases of the project cover a wide range of landscape types across England (Figure 1).

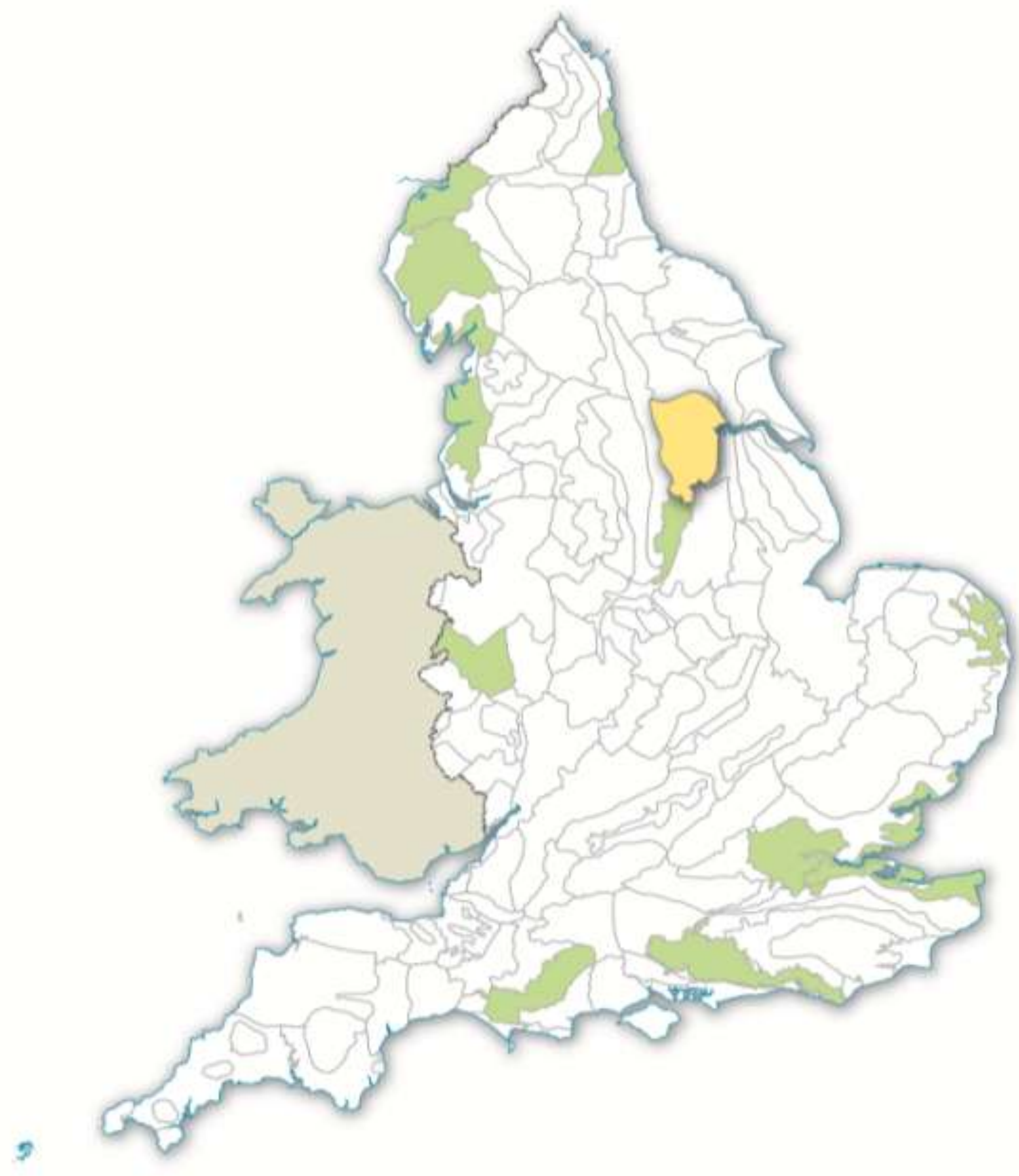

Figure 1 England's 159 National Character Areas, with the 13 areas studied in the two phases of the project highlighted. The Humberhead Levels is shaded in yellow

1.10 This report presents the results of the Humberhead Levels 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 Humberhead Levels. 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. This chapter defines these concepts and describes how they have been used to inform the methodology used.

Sustainable adaptation

2.2 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.

2.3 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?'.

2.4 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

2.5 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).

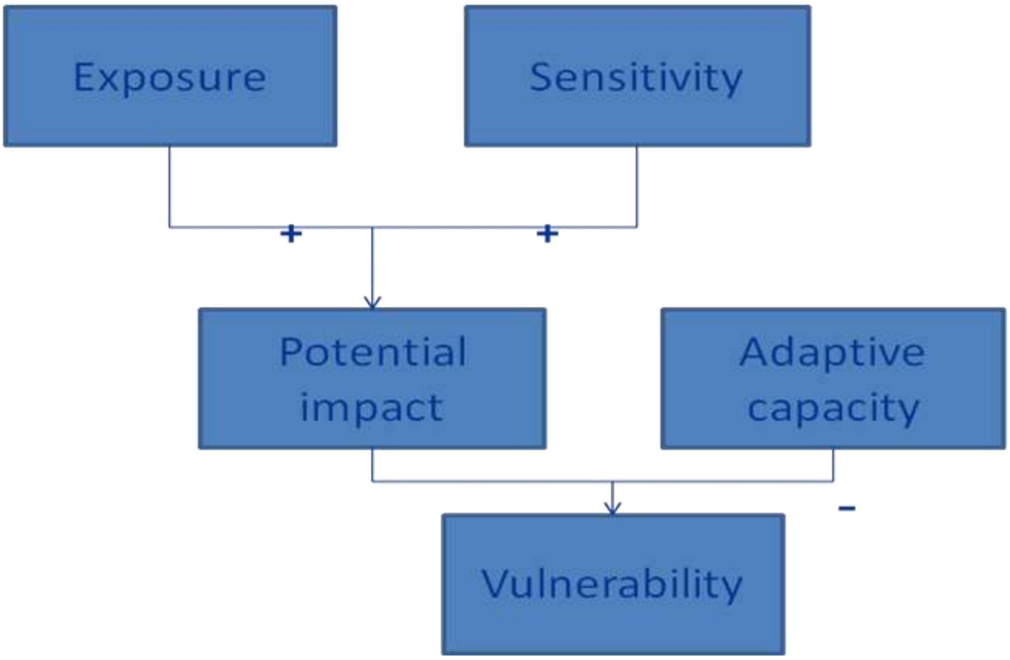

Figure 2 The basic components of vulnerability

2.6 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.

2.7 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).

2.8 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.

2.9 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.

2.10 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.

2.11 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[5], 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

2.12 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.

2.13 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 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.

[5] 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

Landscape as an integrating concept

2.14 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.

2.15 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.

2.16 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).

2.17 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.

2.18 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.

2.19 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.

2.20 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.

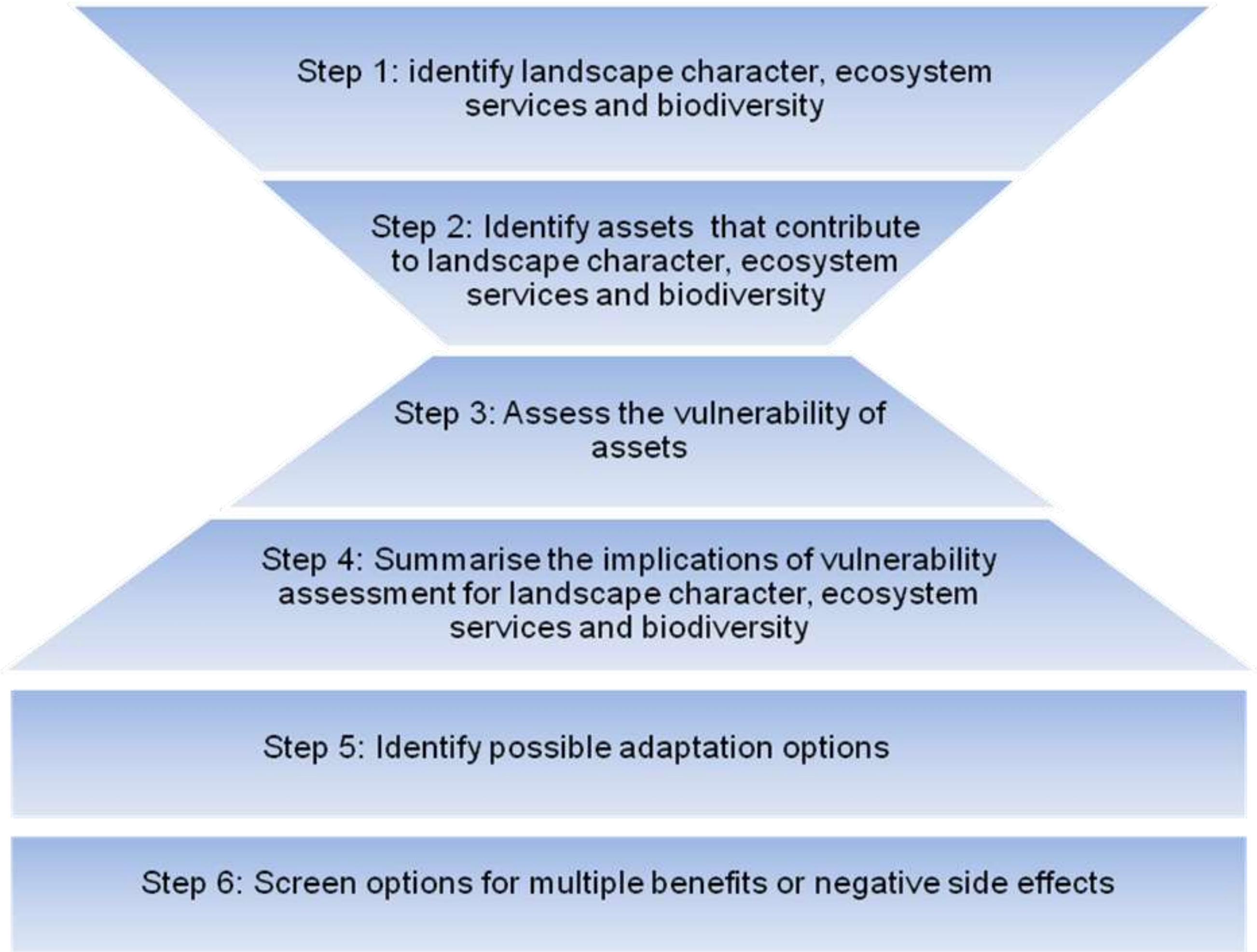

Figure 3 The main steps in the method used to assess vulnerability of the area to climate change and to identify and evaluate possible adaptation options

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

3.3 We identified the landscape characteristics, biodiversity and ecosystem services of the Humberhead Levels NCA by reviewing the current NCA description (Countryside Commission, 2005) and consulting with regional landscape specialists in Natural England who were revising the description of this NCA.

3.4 As urban townscape is not considered in any detail in the NCA description, urban character and ecosystem services are largely excluded from this study. However, although the Humberhead Levels is predominantly rural, parts of the character area are urban in nature, with parts of Doncaster, and Scunthorpe falling within it, and towns such as Goole and Howden wholly contained within it. Expert workshops identified urban greenspace as an asset that may be vulnerable to climate change, and this has been considered alongside other recreational resources in this report.

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

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

- Geology and soils.
- Habitats and species.
- Historic environment.
- Access and recreation.
- Other key elements of landscape form.

3.6 The assets were identified by reviewing the NCA descriptions and through consultation with Natural England regional specialists. In addition, many of the assets were mapped using spatial data held by Natural England. The maps presented in this report illustrate information that we hold 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 internal Natural England staff. Further checking of validity was undertaken at the two stakeholder workshops held in early 2010 (see Step 3 below).

Step 3 – Assessment of the vulnerability of assets to the impacts of climate change

3.8 We assessed the vulnerability of assets in two parts:

- Step 3a – vulnerability assessment combining published information with expert opinion; and
- Step 3b – Correction for evidence gaps.

Step 3a: Vulnerability assessment combining published information with expert opinion

3.9 The vulnerability of each asset to the effects of climate change was assessed, considering exposure, sensitivity and adaptive capacity. We considered vulnerability to both the direct effects of climate change, and the indirect effects (defined here as the effects of human responses to climate change). In assessing vulnerability we considered the following concepts and associated sources of information:

1) **Exposure**

Broad climate change variables consistent with headline messages in UKCP09 and the Yorkshire and Humber Climate Change Adaptation Study (Yorkshire and Humber Assembly, 2009) were used to consider exposure (see example below), alongside consideration of whether assets may be protected from climate changes, for instance by a flood defence. We considered broad trends, such as an increase in winter rainfall, rather than a specific climate change scenario, as experience in previous studies had suggested that there was limited value in trying to predict the effects of specific scenarios, given gaps in our knowledge of natural systems. In addition, the aim was to consider responses that could be valid for a broad range of possible future climates.

Headline messages for Yorkshire and Humber regions from UKCP09 (2080s, medium emissions scenario) and the Yorkshire and Humber Climate Change Adaptation Study:

- 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 3.3ºC; it is very unlikely to be less than 1.7ºC and is very unlikely to be more than 5.4ºC.
- The central estimate of change in winter mean precipitation is 15%; it is very unlikely to be less than 2% and is very unlikely to be more than 33%.
- The central estimate of change in summer mean precipitation is –23%; it is very unlikely to be less than –44% and is very unlikely to be more than 0%.

UKCP09 (Murphy *et al.*, 2009)

Yorkshire and Humber Climate Change Adaptation Study:

- Hotter summers
- Drier summers
- Warmer winter
- Wetter winter
- More frequent storms
- Sea level rise

(Yorkshire and Humber Assembly, 2009)

2) **Sensitivity**

When identifying how an asset might be sensitive to the impacts of climate change, we considered characteristics of the asset, including its condition, extent, tolerance of climate trends, 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 other natural or managed processes (see '**Vulnerability assessment**' above). For biodiversity assets in particular, adaptive capacity can be seen in terms of intrinsic capacity to adapt (either via ecological adaptation, where species may shift their geographical distribution or seasonal activity for example, or via evolutionary adaptation by natural selection) as well as 'adaptive management capacity', whereby vulnerability is reduced by human intervention to ameliorate impacts (Williams *et al*., 2008). The factors we considered here included the current condition of assets (for example, fragmentation of semi-natural vegetation), the presence of hard defences constraining the movement of coastal assets, and current management regimes.

3.10 The project team made an initial assessment of the vulnerability of the natural assets in the NCA, considering the aspects of vulnerability above. The results were recorded on a series of standardised templates, which were circulated to regional technical experts within Natural England, English Heritage, RSPB, the Environment Agency, local authorities and the Wildlife Trusts. This engagement enabled a more detailed compilation of assets and their likely vulnerability. These were presented to a wider group of local experts at two workshops held in January and February 2010.

Workshop with organisational attendees, 21 January 2010

3.11 The first workshop included representatives of Natural England, RSPB, the Environment Agency, local authorities and the Wildlife Trusts, together with the National Farmers Union (NFU) and the Country Land and Business Association (CLA). The session was convened specifically for the project and brought together technical specialists covering the range of areas represented within the Humberhead Levels.

3.12 Working with our initial vulnerability assessment templates, attendees at the workshops were asked whether any assets valuable to the nature of the character area had been omitted. Once attendees had confirmed that the tables were as complete as possible, a voting exercise was undertaken to enable the most valued, and the most vulnerable assets within the character area to be identified.

3.13 Each attendee was given a number of 'votes' to allocate to assets which they felt were most valuable within each category (ie habitats, geodiversity and soils, historic environment, access and recreation and other landscape assets). Attendees were then allocated a separate set of 'votes' which they used to indicate which assets in each category they felt would be most vulnerable to the impacts of climate change, using the definitions in Table 1 as a guide. Votes were not transferable between categories and no attempt to prioritise issues in one category over issues in another category was made, as participants were not considered to represent an equal balance of expertise across sectors. Corrections for evidence gaps have been made or further discussion qualified if responses of assets to climate change were appropriate.

3.14 The vulnerability voting exercise allowed a number of 'priority' assets to be identified and scored according to their vulnerability to impacts of climate change (Table 1). Scores are represented visually across a 3-tier rating as being either relatively more vulnerable, moderately vulnerable, or less vulnerable. Voting scores across the 3 tiers of vulnerability were consolidated for each asset and are presented as vulnerability ratings in Appendix 1, alongside a value score in brackets.

Humberhead Levels Partnership workshop, 10 February 2010

3.15 Businesses, landowners/managers and communities all have an important part to play in helping to achieve sustainable land management to meet the challenges, save the wetlands and reap benefits for nature, communities and the landscape.

3.16 A second workshop was undertaken with the Humberhead Levels Partnership to check and confirm the results of the initial assessment and first workshop. (The partnership comprises Natural England, Environment Agency, North Lincolnshire Council, Doncaster Metropolitan Borough council, the RSPB and the Wildlife Trusts, and aims to address the challenges facing the character area through sustainable land management practices (Humberhead Levels Partnership, 2008).) The members of the Humberhead Levels Partnership are locally active in the character area and were well placed to assess and qualify the priorities from the first workshop due to their local knowledge and experience, collectively and individually. Based on this workshop discussion and subjective assessment, minor alterations were made to the significance and vulnerability rating of a number of assets, although the partnership generally agreed with the conclusions of the first workshop. Discussion followed on adaptation responses for more vulnerable assets (not considered at the first workshop), considering issues and constraints, identifying and acknowledging interactions and complexities, and identifying potential delivery mechanisms.

3.17 The output of both workshops was an updated version of the vulnerability tables (Appendix 1) and are summarised in Section 4 as part of the Results chapter.

Table 1 Vulnerability ratings used in this report

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.

3.18 While the results of the assessment of all the assets are shown in this report for the sake of completeness, wherever possible the ‘priority assets’ identified by the second workshops have been mapped (see Step 2).

Step 3b: Correction for evidence gaps

3.19 In carrying out the vulnerability assessment in Step 3a, the views of specialists within Natural England were combined with the views of workshop participants. However, we felt that not all organisations were represented and contributors were from varying sectors within their organisations, resulting in more emphasis being placed on issues where there was most collective knowledge. In addition, although historic environment specialists commented on the initial templates, none attended the workshops.

3.20 It was not possible to fully correct for this, as some impacts of climate change have been researched in more detail than others. However, we made an additional effort to identify valuations that were not aligned to evidence from elsewhere during the writing of this report. This involved examining the relative vulnerability ratings and identifying any that seemed anomalous in light of available evidence, the comments received from consultees, or the findings of other vulnerability studies undertaken as part of the national project. This was undertaken via a telephone comparison with the author of the neighbouring Sherwood NCA study and at a review session held with other vulnerability study authors. Where the final vulnerability ratings differ from the results of the stakeholder analysis, the reason for changing the rating is detailed in the Vulnerability tables in Appendix 1.

3.21 Some features, such as iconic species, were not scored at the stakeholder workshops. These are noted as having no score in the results chapter. Where stakeholder analysis or evidence indicated a strong case for giving iconic species a vulnerability rating, this is indicated in the results chapter.

Step 4 – Identification of potential major changes to landscape character, ecosystem services and biodiversity

3.22 Having assessed the vulnerability of the important natural assets of the Humberhead Levels, we considered what the combined effects of changes to assets deemed to be ‘moderately vulnerable’ and above would be on the overall landscape character, ecosystem services and biodiversity of the NCA. We considered the effects on each of the separate elements of landscape character, ecosystem services and biodiversity that had been identified in Step 1. The results were then summarised as a set of statements about potential major changes. This evaluation was based on the results of the assessment excercise carried out in Step 3, local knowledge of the project team, examination of available literature and through consultation with Natural England regional specialists.

Steps 5 and 6 – Identification and evaluation of potential adaptation actions

3.23 Potential adaptation actions to address the vulnerability of the assets of the Humberhead Levels were identified from a combination of published literature (for example, Hopkins *et al*., 2007), along with expert opinion from Natural England specialist staff.

3.24 Again, we aimed to identify responses to climate change which are valid for a broad range of climate variables suggested by the UKCP09 scenarios (for instance, increase in frequency of extreme rainfall events and extreme temperature events such as heat-wave), rather than focusing on a specific narrow scenario.

3.25 A number of principles were followed when deciding 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 is not 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).

3.26 We used a matrix to screen potential adaptation actions in order to identify ‘win-win’ and ‘low regrets’ actions and assess whether individual actions had a positive, negative or neutral effect on the key landscape character, ecosystem services and biodiversity categories. By noting those actions that were repeated under several headings of landscape character, biodiversity and ecosystem services in Step 5; we identified actions that would address multiple aspects of vulnerability.

3.27 The screening matrix (Appendix 4) was also used to identify where conflict might arise between adaptation actions. Where negative or uncertain effects of an adaptation action were noted, actions were refined to lessen or reduce such effects wherever possible.

3.28 Where possible, we used the concept of adaptive management to inform our identification of potential adaptation actions. Adaptive management has been defined as ‘*a structured process* *of "learning by doing" that involves much more than simply better ecological monitoring and response to unexpected management impacts. In particular, it has been repeatedly argued that adaptive management should begin with a concerted effort to integrate existing interdisciplinary experience and scientific information into dynamic models that attempt to make predictions about the impacts of alternative policies*' (Walters, 1997).

3.29 Once adaptation actions had been identified for specific assets in the Humberhead Levels, they were grouped and summarised under the major potential changes to landscape character, ecosystem services and biodiversity that had been identified, to place the focus on lessening the vulnerability of the overall benefits provided by the Humberhead Levels landscape rather than the individual assets in it. In addition, we identified a number of potential 'strategic' adaptation actions that could help to provide a framework for adaptation across the whole Character Area.

4 Results

Part 1 – Description of the landscape 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 services, considering the range of different asset types (though these headings are not explicitly used in this section of the report):

- Geology and soils.
- Habitats and species.
- Access and recreation.
- Historic environment.

Landscape character

4.2 The Humberhead Levels NCA is bounded to the west by the southern magnesian limestone ridge (from which there are views over the Levels) and to the east by the Yorkshire Wolds and the Northern Lincolnshire Edge with Coversands NCA (from where there are also views). To the north, the NCA merges gradually into the slightly more undulating landscape of the Vale of York at the line of the Escrick moraine and to the south, past Retford, it merges with the Trent and Belvoir Vales. The River Ouse, which is one of the main rivers in this NCA, enters the area from the Vale of York to the north and exits into the Humber Estuary to the east. The River Trent enters the NCA from the Trent and Belvoir vales (Nottinghamshire) to the south and joins the Humber Estuary to the east. Other rivers enter the area from the west - all destined for the Humber Estuary. Approximately 7% of the NCA is classed as urban, 76% is agricultural, 4% is woodland and 3% falls within SSSI designations (Figure 4).

4.3 The key landscape characteristics of the Humberhead Levels NCA have been drawn from internal work being undertaken by Natural England to promote an integrated approach to addressing the challenges and opportunities facing the natural environment throughout the Humberhead Levels (Natural England, undated a). This work draws from established sources such as the National Character Area description for 'National Character Area 39: The Humberhead Levels' (Natural England, undated c), and the Natural Area description (Natural England, undated d). These key landscape characteristics are set out below.

4.4 **Low-lying area of the former pro-glacial Lake Humber, often falling below the mean water level with drift deposits including glacial tills, peat, gravel and wind-blown sand, which give local variation to landscape character.** The Humberhead Levels occupies the area of the former 'pro-glacial' Lake Humber, formed from the trapped melt water of glaciers. During the last glaciation, a glacier extended south across this area, reaching almost as far as Doncaster. The main glacial front was at Escrick, where it deposited a ridge of till, sand and gravel known as the Escrick Moraine. The Escrick Moraine marked the northern limit of the extensive Lake Humber which was impounded by the blocking of the Humber gap by another ice front between Brough and Winterton to the east.

4.5 The character of the Humberhead Levels is strongly influenced by alluvial deposits which were deposited by the lake. The lake was filled with sediment, predominantly in the form of laminated clays up to 20 metres thick. These create wet, gleyed soils, locally overlain by peat forming the important raised mires of the area. Near and at the base of the peat are the remains of a buried forest. There are also extensive modern floodplain deposits and local deposits of wind-blown sand which create more free-draining, sandy, brown earths. The latter require high fertiliser input for cultivation and so, in places, support birch and oak woodland, heathland, or conifer plantations.

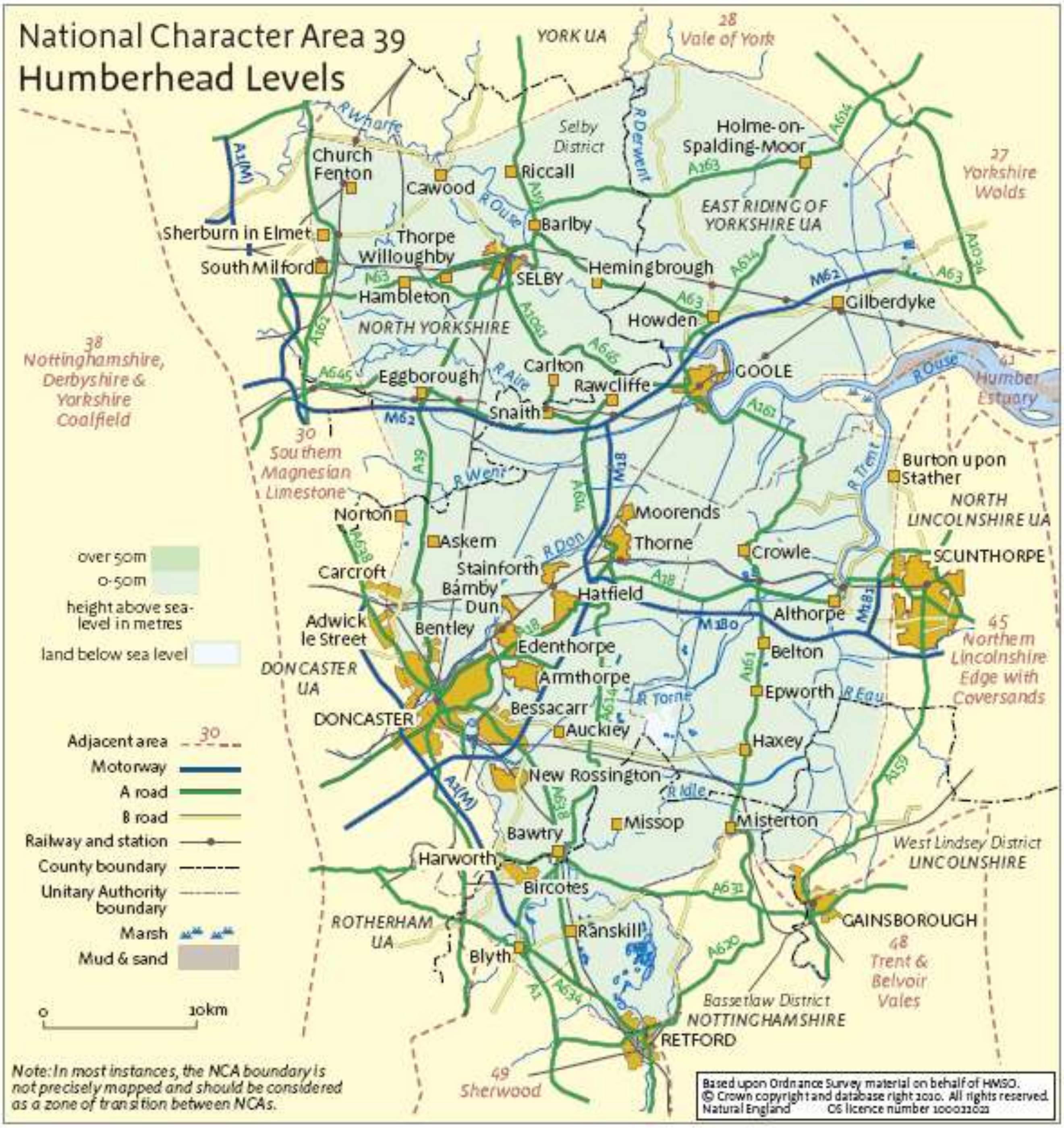

Figure 4 Map of the Humberhead Levels NCA

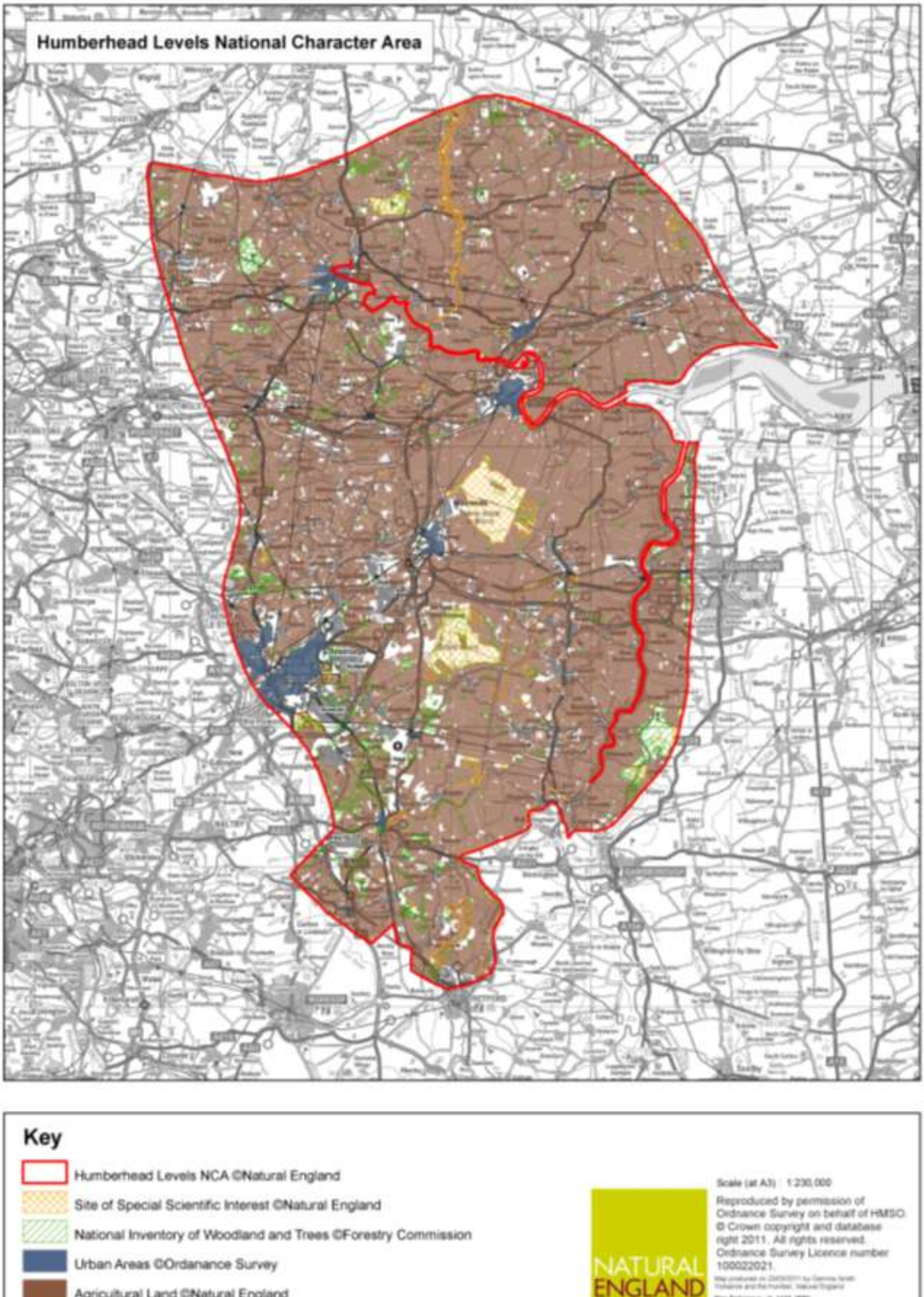

Figure 5 Spatial distribution and extent of land use and SSSIs in the Humberhead Levels

4.6 **Waterlogged archaeological remains and palaeo-environmental deposits of international importance in the Trent floodplains.** Among the significant factors determining the character of historic environment in the Humberhead Levels NCA are:

- Lighter soils in the north and south of the Character Area.
- A wet and marshy landscape in the centre of the Character Area.
- A complex system of rivers and dykes in the centre of the Character Area.
- The drainage and warping of large areas of land.
- Peat cutting.
- Periods of enclosure.

4.7 Amongst the significant archaeological finds are the oldest plank boats in the world, outside of Egypt, which were found near Thorne. A Bronze Age pathway through 'Thorne Forest', laid approximately 3,000 years ago, has also been unearthed (Natural England undated, d).

4.8 **Essentially flat, very open character with distant views and big skies, and occasional rising ground formed by ridges of sand and outcrops of Mercia Mudstone.** The landscape is formed on drift deposits which overlie bedrock of Triassic Mercia Mudstones. These drift deposits have the greatest influence on the landscape, creating the flat or gently undulating topography. The Humberhead Levels are a predominantly flat, low lying agricultural landscape including the floodplains and 'warp land' of a number of rivers which drain into the Humber.

4.9 In some places there are local variations in topography caused by differences in the underlying deposits. There are higher ridges where the underlying sandstone or mudstone rises above the alluvium or where there are mounds of glacial deposits. The Isle of Axholme, for example, is formed of Mercia Mudstone and blown sand and is elevated above the surrounding levels to form a small, but distinct, area of landscape.

4.10 **Extensive floodplains, washlands, saltmarsh and traditionally grazed alluvial flood meadows ('Ings') associated with navigable rivers.** The Humberhead Levels includes the broad floodplains of several major, often navigable, low-lying rivers which drain to the Humber. They include the Derwent, Don, Torne, Idle, Went, Aire, Ouse and Trent. The land is rich and intensively farmed in generally very large, open, geometric fields usually divided by dykes. This low-lying, drained levels landscape is widespread around Goole, northwards up the valley of the Derwent and, south of the Humber, in the Ouse and Trent levels. These floodplains are important for their wetland vegetation and as habitats for wintering and migrating birds.

4.11 There are a number of man-made navigable waterways in the Character Area, including the Aire and Calder Navigation and the Stainforth and Keadby Canal which flow through the Humberhead Levels.

4.12 **Peat bogs and raised mires.** The peat bogs and raised mires of Thorne, Crowle, Goole and Hatfield Moors, and the smaller peatlands of Epworth Turbary and Haxey Turbary are of particular ecological and historical importance. Peat cutting has significantly shaped the landscape in places such as Thorne, Goole, Hatfield and Crowle Moors and dates back hundreds of years. Initially taken as fuel by local people, by the mid 19th century it was being extracted for horse and cattle litter, and later for use in horticulture (Thorne-Moorends Town Council, undated). The area also provides evidence of the development of different peat cutting techniques, of English, Dutch and Irish origin. The larger peatlands in particular provide a sense of wilderness in what is otherwise a highly managed landscape.

4.13 **Rich and fertile farmland.** Most of the Humberhead Levels NCA is intensively farmed. High input, essentially 'industrialised' cropping systems dominate the area, with cereals and root crops predominating. Livestock farming exists to a lesser extent in the Humberhead Levels involving sheep, cattle, poultry and pigs, although the latter have significantly dropped in numbers since 2000.

4.14 The area also includes substantial areas of 'warp' land, one of the most productive cropping areas in Britain. It is thought that the earliest attempts at land drainage may date back to Roman times. The Dutch engineers, who drained vast areas of the Humberhead Levels, introduced the practice of large-scale 'warping' in which areas of farmland were deliberately inundated with seasonally impounded tidal waters which deposited layers of alluvial silt over the existing soils to enrich them. Many of the drainage channels were used for this purpose and have names such as the 'Swinefleet Warping Drain'. Farmland, if sympathetically managed, provide feeding areas for cranes and marsh harriers.

4.15 **Small areas of carr woodland and rare alder woodland.** Small areas of carr woodland, made up of scrubby grey willow, birch and alder and older patches of ash, field maple and oak, occur. A few examples of nationally scare alder woodland exist in the Humberhead Levels.

4.16 **Historic landscape around the Isle of Axholme and north of Doncaster.** The Humberhead Levels includes a number of distinctive historic landscapes. Important historic landscapes include the internationally important remnant open field landscape on the Isle of Axholme, the unique cable landscape near Thorne, and the 'warps' around Goole. A more enclosed landscape is found north of Doncaster, around Fishlake and Sykehouse, including, small thickly hedged fields, hedgerow trees, green lanes, hay meadows and remnants of ridge and furrow fields.

Plate 1 Strip farming looking towards Belton from Hoggatt Hill at Epworth

4.17 **Large geometric fields bounded by dykes and ditches, canals and altered river courses.** The cultural and historic landscape pattern is strongly associated with drainage, which has mostly been carried out since the 17th Century, although it is thought that the earliest attempts at land drainage may date back to Roman times. The legacy of drainage is evident in the large geometric fields usually bounded by dykes and ditches (which support rare aquatic and emergent plants) and assets such as pump houses, sluices and small brick bridges.

4.18 Often rivers are contained by flood embankments. Old river courses may be visible, such as that of the Don. Canals such as the Stainforth and Keadby Canal and the Aire and Calder Navigation, along with river systems, subdivide the landscape.

4.19 **Remnant heath, birch and oak woodlands alongside large isolated conifer plantations.** Native woodlands are scarce, confined to small areas of wet woodland. Areas of birch and oak woodland can be found alongside modern conifer plantations and remnant lowland heaths on sandy soils near Selby between the Rivers Torne and Idle and near Bawtry in the south. Otherwise, tree cover is very limited.

4.20 **Settlements and roads are located on higher ground.** Settlements and roads within the Humberhead Levels are often located on higher drier ground. Settlements typically consist of small linear villages, scattered farmsteads and occasional larger market towns. The local vernacular is characterised by 'Barton' red brick, pantile and occasional slate.

4.21 While predominantly rural in character, the character area lies in close proximity to a number of larger urban settlements such as Leeds, York, Kingston-upon-Hull, Sheffield and Rotherham. The major part of the large town of Doncaster lies within the NCA, and the smaller towns of Goole, Howden, Selby, Thorne, Bubwith and Bawtry constitute significant settlements placed within the character area. A small part of Scunthorpe also overlaps the NCA.

4.22 **Isolated farmsteads, former monastic granges, specialist steadings and high concentration of moated sites.** Isolated farmsteads which relate to shrunken settlements, former monastic granges and specialist steadings can be found throughout the Humberhead Levels. There is a high concentration of moated sites around Isle of Axholme and north of Doncaster.

4.23 Countryside Quality Counts data (Countryside Quality Counts, 2007) shows that landscape character continues to evolve in the Humberhead Levels, particularly as a result of changing farming practices and development pressures (see example below). At the time of writing these changes were influencing the updating of NCA descriptions in a separate Natural England project.

Recent changes and trends of Landscape character

Countryside Quality Counts (CQC) data suggests that changes in agricultural character and development patterns continued to transform the area between 1999-2003. Specific recent changes and trends recorded in CQC were as follows:

- An increased uptake of Woodland Management Grants and improved management of existing blocks between 1999 and 2003. About 20% of the woodland cover was covered by a Woodland Grant Scheme.
- A limited uptake of agri-environment agreements for boundary management: between 1999-2003 the total length of agreements was equivalent to 2% of the total length, although it is to be noted that the fields are usually divided by dykes with few hedgerows.
- A decline in mixed farming and general cropping, a lowering of the water table as a result of drainage and pumping to abstract water and drying out of peat bogs and loss of habitats.
- Pressure on the rural character of the area as a result of growth pressures (housing, transport and industrial) particularly in nearby urban and fringe areas in the north.
- A weakening of historic character due to a limited uptake of Countryside Stewardship Agreements for the management of the historic landscape (none of the remaining parkland was covered by a Historic Parkland Grant and only 8% was covered by an agri-environment scheme; 76% of historic farm buildings remained unconverted, of which about 77% were intact structurally).
- Biological river water quality and chemical water quality in 1995 was predominantly excellent and was maintained to 2003.

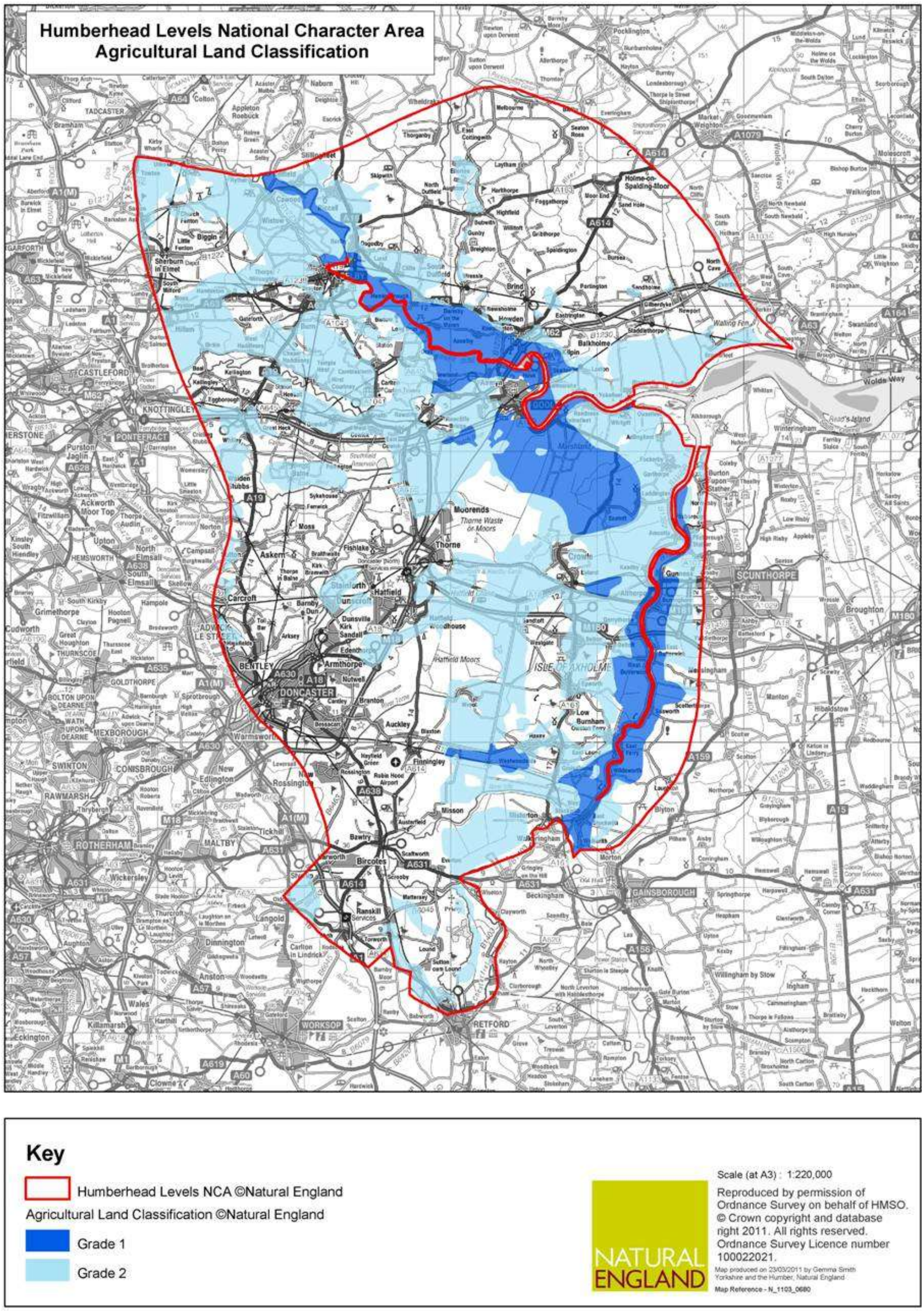

Figure 6 Agricultural Land Classification Grade 1 and 2 distribution and extent in the Humberhead Levels

Ecosystem services

Food and biomass production

4.24 The Humberhead Levels is a highly productive farming area: 44 percent of the land area is classed as grade 1 or 2 in the Agricultural Land Classification (Figure 6). High input, essentially 'industrialised' cropping systems are the norm, with cereals and root crops predominating. Livestock farming exists in the Humberhead Levels involving pigs, poultry, beef cattle and dairy herds. As a primarily arable cropping area, numbers of cattle and sheep are relatively low, and have stayed low over the past decade. However, the numbers of pigs has dropped significantly.

4.25 The types of agriculture present in the NCA are largely determined by soil types. To the North of Doncaster, a small area of heavy clay soil traditionally supports smaller-scale pastoral agriculture. Livestock farming are generally located in the river valleys on poorer wetter soils and in the pastoral areas of Fishlake and Sykehouse.

4.26 The proximity of major power stations associated with the Yorkshire coalfields and large rivers means that biomass crops grown in the Humberhead Levels have a readily accessible market.

Freshwater provision and drainage

4.27 The use of land for agriculture means that freshwater for agricultural irrigation is extremely important, as is the drainage of land to enable cultivation. Water is widely extracted from groundwater sources and rivers such as the Derwent (for instance, at Loftsome Bridge water treatment works). Continued drainage and water extraction for irrigation has lowered the water table (Countryside Agency, undated).

4.28 Productive fissure flows and moderate fissure flows can be found in parts of the NCA. Such flows can support abstractions and may feed wetlands.

Climate regulation

4.29 Soils and biomass can perform an important in carbon sequestration to support climate change mitigation. Peat soils have a particularly important role in storing carbon and within the Humberhead Levels there are significant areas of raised bogs such as Thorne and Hatfield Moors. Peatlands within the Humberhead Levels cover 3,500 hectares. The degraded condition of many peatlands means many are losing carbon to the atmosphere (Natural England 2010a).

4.30 All vegetation growth sequesters carbon from the atmosphere, and soils also store carbon to varying degrees (Batjes, 1996; Swift, 2001). While soils in the Humberhead Levels, other than peat, generally have a low carbon content, wetland and woodland ecosystems, for example are a significant carbon store (Millennium Ecosystem Assessment, 2005; Lloyd, 2006; Read *et al*., 2009). Certain agricultural practices that increase organic matter or retain moisture in the soil can also aid the absorption of carbon.

Flood water storage

4.31 The natural environment can perform an important function in supporting climate change adaptation. Flood plains play a crucial role in regulating the flow of water downstream (O'Connell *et al*., 2004; The Pitt Review, 2008; Morris *et al*., 2009). There are numerous areas within the floodplains of the main rivers and their tributaries which provide flood storage (Morris *et al*., 2008; **www.rathmell.org.uk/rathmell-village-7285-farmingnews.php**; **www.yorkshirepost.co.uk/news/country-view/farming/a_day_to_celebrate_the_return_of_the_wetlands_1_2989152**) and therefore are already acting to protect nearby properties and businesses. The many areas of wetland perform similar services.

4.32 Large parts of the Humberhead Levels lie in flood zones 2 and 3, including many settlements such as parts of Doncaster and Goole, and sites such as Thorne and Hatfield Moors. Significant areas, such as along the routes of Aire and Don, are identified as flood storage areas by the Environment Agency (Environment Agency 2010 a, b).

Water filtering and purification

4.33 The natural processes of floodplains and flood storage areas (including wetlands) also perform a filtering function, allowing sediment rich water carried in flood waters to be deposited, thus improving water quality. Deposition of substances on floodplains also acts to enrich the quality of land.

Soil formation

4.34 Soils are an integral part of any land-based ecosystem, and interact constantly with the organisms, atmosphere, climate and geology (Brady and Weil, 2008). Soils process water and nutrients for the plants we eat, decompose and recycle our waste, moderate flooding, absorb carbon and provide raw materials and substrate for development of infrastructure. Given the strong agricultural character of the NCA, soil formation is a particularly important service. They are the building blocks of landscapes.

Table 2 List of soils within the NCA, analysed using a soilscape typology which classes soils into 14 main types within the Humberhead Levels

	Area (ha)	%
Freely draining lime-rich loamy soils	2,407	1.40
Freely draining slightly acid loamy soils	3,904	2.27
Slightly acid loamy and clayey soils with impeded drainage	2,281	1.33
Freely draining slightly acid sandy soils	18,633	10.85
Freely draining very acid sandy and loamy soils	2,106	1.23
Naturally wet very acid sandy and loamy soils	23,915	13.92
Slowly permeable seasonally wet acid loamy and clayey soils	1,368	0.80
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	41,370	24.08
Loamy and clayey floodplain soils with naturally high groundwater	10,381	6.04
Loamy and clayey soils of coastal flats with naturally high groundwater	37,933	22.08
Loamy soils with naturally high groundwater	13,920	8.10
Loamy and sandy soils with naturally high groundwater and a peaty surface	6,125	3.57
Raised bog peat soils	3,573	2.08
Fen peat soils	3,017	1.76

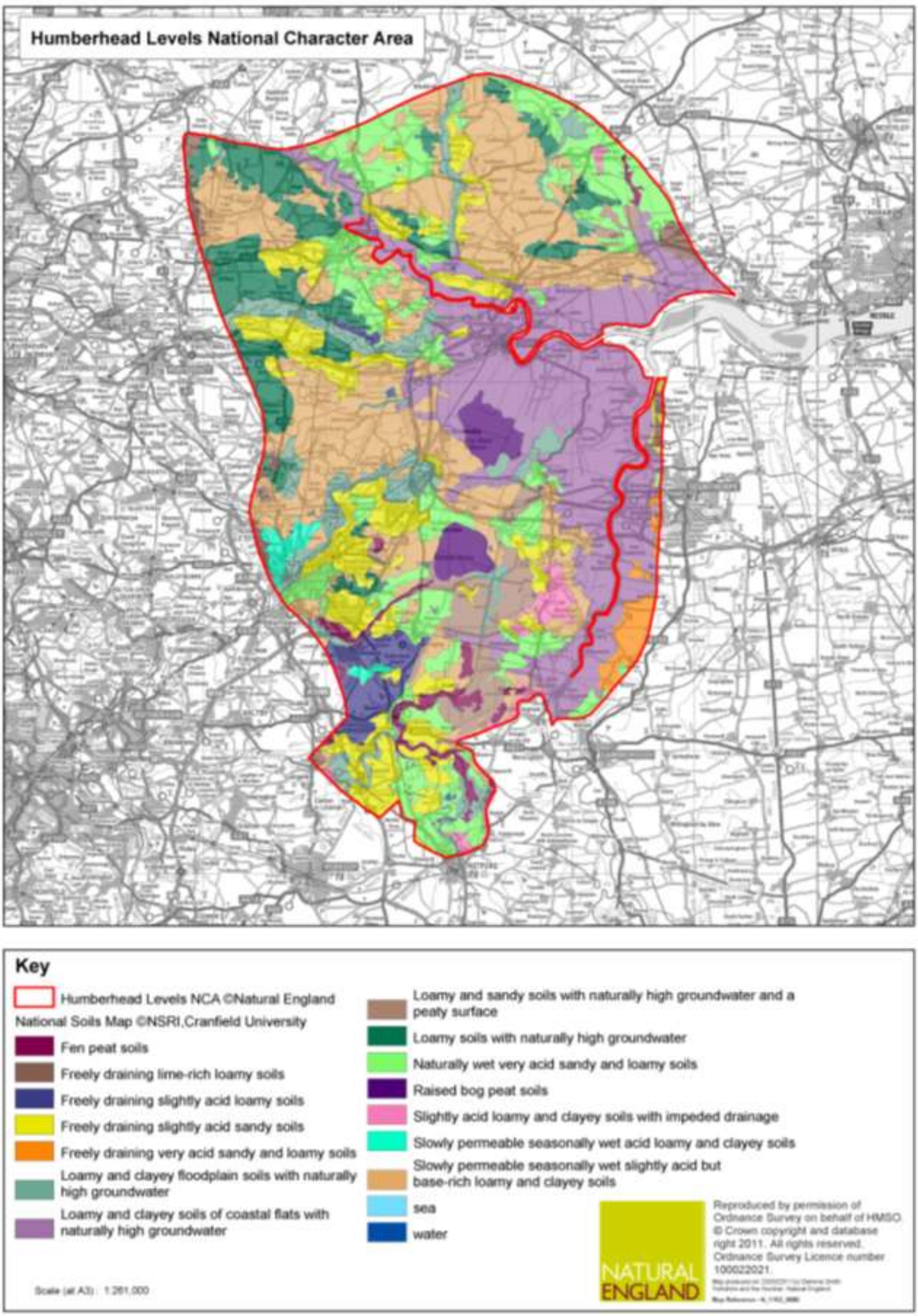

Figure 7 Distribution of soil types in the Humberhead Levels

Pollination

4.35 Pollination is a critical ecosystem service, without which many plants and the animals and humans that depend on them would find it difficult, if not impossible, to survive. Although many plants are pollinated 'abiotically' (pollination by non biological processes such as wind), many crops rely on invertebrates to pollinate them. While the Humberhead Levels' cereal production would not suffer significantly if invertebrate pollination broke down, as all cereals are abiotically pollinated and many vegetables produced in the area are derived from seed that is pollinated by seed houses elsewhere, many wild plants rely on invertebrate pollination to set seed.

Recreation and health

4.36 There is considerable evidence that using the natural environment for recreation, including walking, can have both physical and mental health benefits (Maas *et al*., 2009; LGIU 2010). Accessible green spaces and rights of way constitute a key means of encouraging healthier lifestyles (Coombes *et al*., 2010)[6], both for more deprived communities and the wider population as a whole.

4.37 While predominantly rural in character, the Humberhead Levels lies in close proximity to a number of larger urban settlements. Although several of these are among the least deprived, according to the range of deprivation indicators that contribute to the index of multiple deprivation, there are also significant areas which are less well off[7]. Provided they have the means to travel to nearby open spaces, for such communities, open space represents a valuable free resource for recreation.

4.38 Key recreational assets within the NCA include:

- Three National Nature Reserves (NNRs), including the Humberhead Peatlands NNR, Skipwith Common NNR and Lower Derwent Valley NNR (Figure 8).
- Ten Local Nature Reserves (LNRs).
- Part of the Transpennine Trail crosses the area.
- Four Healthy Walks Initiatives.

4.39 The largest of the NNRs is the Humberhead Peatlands, which covers an area of 2887.5 hectares, features way-marked trails, and Thorne Moor is a significant area of Open Access land. Skipwith Common is the region's newest NNR, designated in December 2009. LNRs offer opportunities for recreation and education. Sites such as Eastrington Ponds LNR are regularly used for countryside events, educational visits by local schools, and informally by walkers.

4.40 The Transpennine Trail is a long distance signed route for walkers and cyclists, running from Southport in the west to Hornsea on the east coast, and runs through the Humberhead

---

[6] A team of researchers from the University of Bristol and East Anglia recently analysed the connection between green space and public health in the city of Bristol. The study, supported by Natural England, compared extensive data on quality of life against a detailed inventory of parks, urban woodlands, footpaths and other green sites in the city. The results showed that people living closer to green spaces were more physically active, and were less likely to be overweight or obese. These trends were apparently independent of people's income or social group; the most significant findings showed that people who lived farthest from public parks were 27 percent more likely to be overweight or obese (Coombes *et al*., 2010)

[7] Lower layer super output areas are geographical areas that are automatically generated to create areas that are as consistent in population size as possible (**www.datadictionary.nhs.uk/data_dictionary/nhs_business_definitions/l/lower_layer_super_output_area_de.asp?shownav=1**)

Levels, connecting towns such as Doncaster to other towns such as Selby and Howden in the NCA. The northern extension route of the Trail also connects Selby to York.

4.41 There are a number of navigable waterways in the Humberhead Levels, including the Aire and Calder Navigation and the Stainforth and Keadby Canal, which provide a recreational resource for boats and towpath users (walkers, cyclists).

4.42 There are a range of smaller resources such as footpaths, bridleways (Figure 8) and local accessible open spaces, which provide local recreation and can encourage exercise and healthier lifestyles of local people. Several settlements have active healthy walking groups operating within them, including Doncaster, Norton, Gainsborough, Selby, ‘Step to It Retford’ and North Lincolnshire Health Walks Partnership. These all operate from locations within or on the border with the Humberhead Levels.

4.43 Levels of access to the countryside vary across the NCA, and aggregate data on a range of assets such as public rights of way and Local Nature Reserves reveal that a number of areas have a particularly poor access network, such as between Holme on Spalding Moor and Gilberdyke, and between Crowle and Fockerby. Other areas have a good access network, such as to the north of Selby and around Thorne[8].

4.44 The quality of green space is also important in encouraging people to use it and so derive health benefits. While information on the quality of individual green spaces can be difficult to obtain, there were no Green Flag or Green Pennant awarded green spaces in the Humberhead Levels at the time of writing. Data available on the ecological quality of SSSI sites in the Humberhead Levels, shows that while the majority of SSSI units are either in ‘favourable’ or ‘unfavourable recovering’ condition, there are a significant minority of SSSI site units that are either ‘unfavourable declining’ or ‘unfavourable no change’. Where access is available to these sites, the perception that the user is experiencing a high quality environment may be diminished.

[8] Datasets contained in the aggregated data: Agri-environment scheme permissive access (routes and open access), CROW access land (including registered common land and Section 16), Country Parks, Cycleways (Sustrans Routes) including Local/Regional/National and Link Routes, Doorstep Greens, Local Nature Reserves, Millennium Greens, National Nature Reserves (accessible sites only), National Trails, Public Rights of Way, Forestry Commission ‘Woods for People’ data, Village Greens – point data

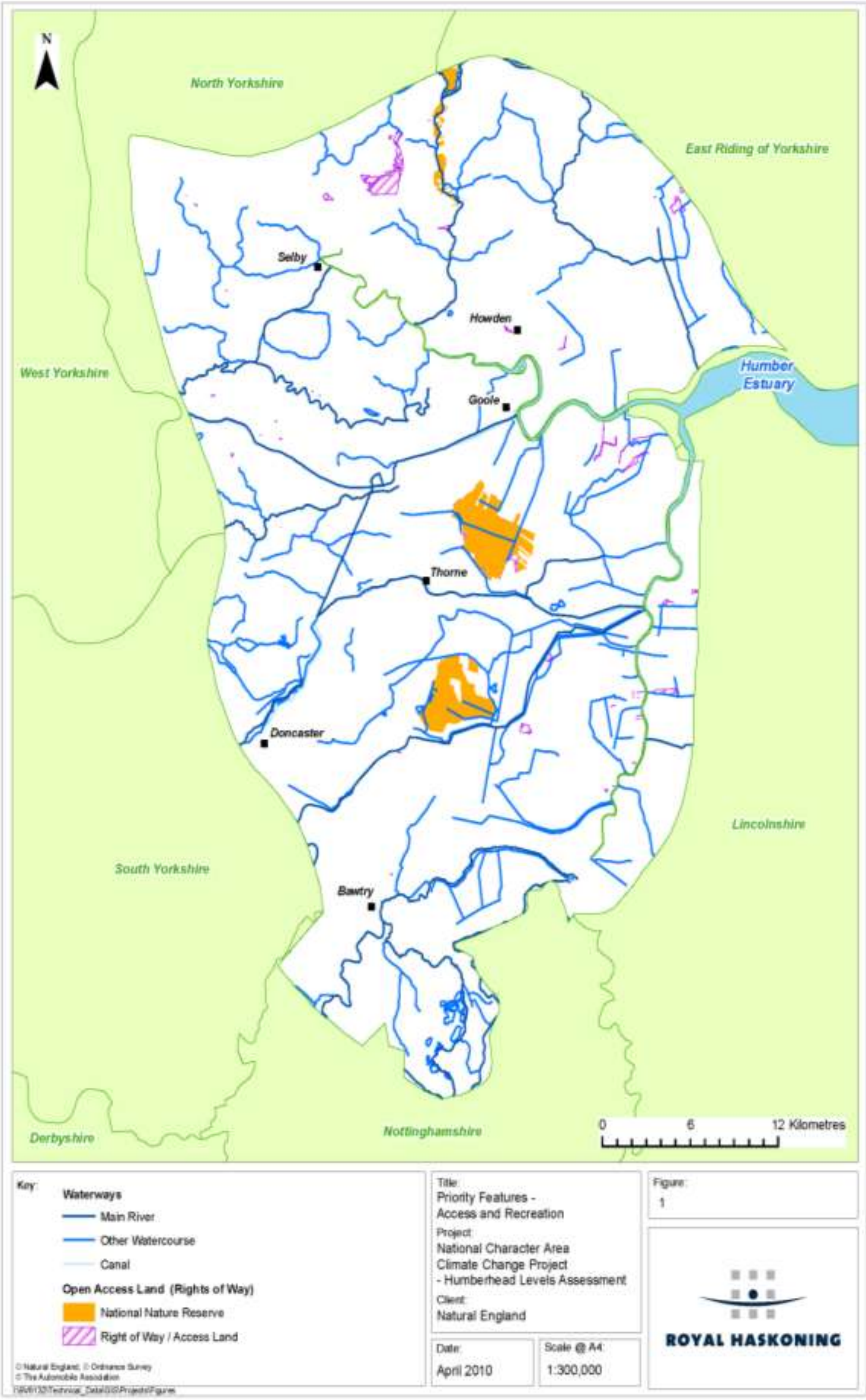

Figure 8 Priority features – access and recreation

Geological, archaeological and historical knowledge

4.45 The human components of the physical landscape tell an important story about the development of agriculture in particular, but also society more widely, and the significant areas of peat in the NCA contain hugely important pollen records and preserved human artefacts.

4.46 Key historical knowledge assets in the NCA include:

- Commons, such as Skipwith, Allerton and Thorne and Hatfield, and their associated turbaries (Figure 9).
- Prehistoric settlements on sand and gravel outcrops and their associated field systems.
- Parklands.
- Roman farmsteads, roads, field systems, salterns and kilns (Figure 9).
- Mediaeval landscapes, such as around the Isle of Axholme.
- Ecclesiastical sites, including sites such as Archbishops Palace at Cawood, and Selby and Howden priories.
- Military defences.
- Palaeo environmental records and remains in alluviated valleys.
- Bog oaks.
- Iron age and Romano British industrial sites.
- Historic communication routes.
- Ancient trees.
- Marine archaeological resources.

4.47 There are also a number of important geological sites in the area, some a legacy of former mining activity. Scrooby Top Quarry Site of Special Scientific Interest (SSSI) and Styrrup Quarry SSSI both lie in the extreme south of the NCA. The former is a working quarry, the latter non-working, and both provide exposures of the Triassic Sandstone, 'Nottingham Castle Formation'. As well as nationally designated SSSIs, there are also regionally important sites for geology. Doncaster, for example, has four Regionally Important Geological Sites (RIGS) (Dunsville Quarry, Blaxton Common, and Common Lane Quarry, each on the Sherwood Sandstone, and Hurst Plantation Quarry, on glaciofluvial sands and gravels).

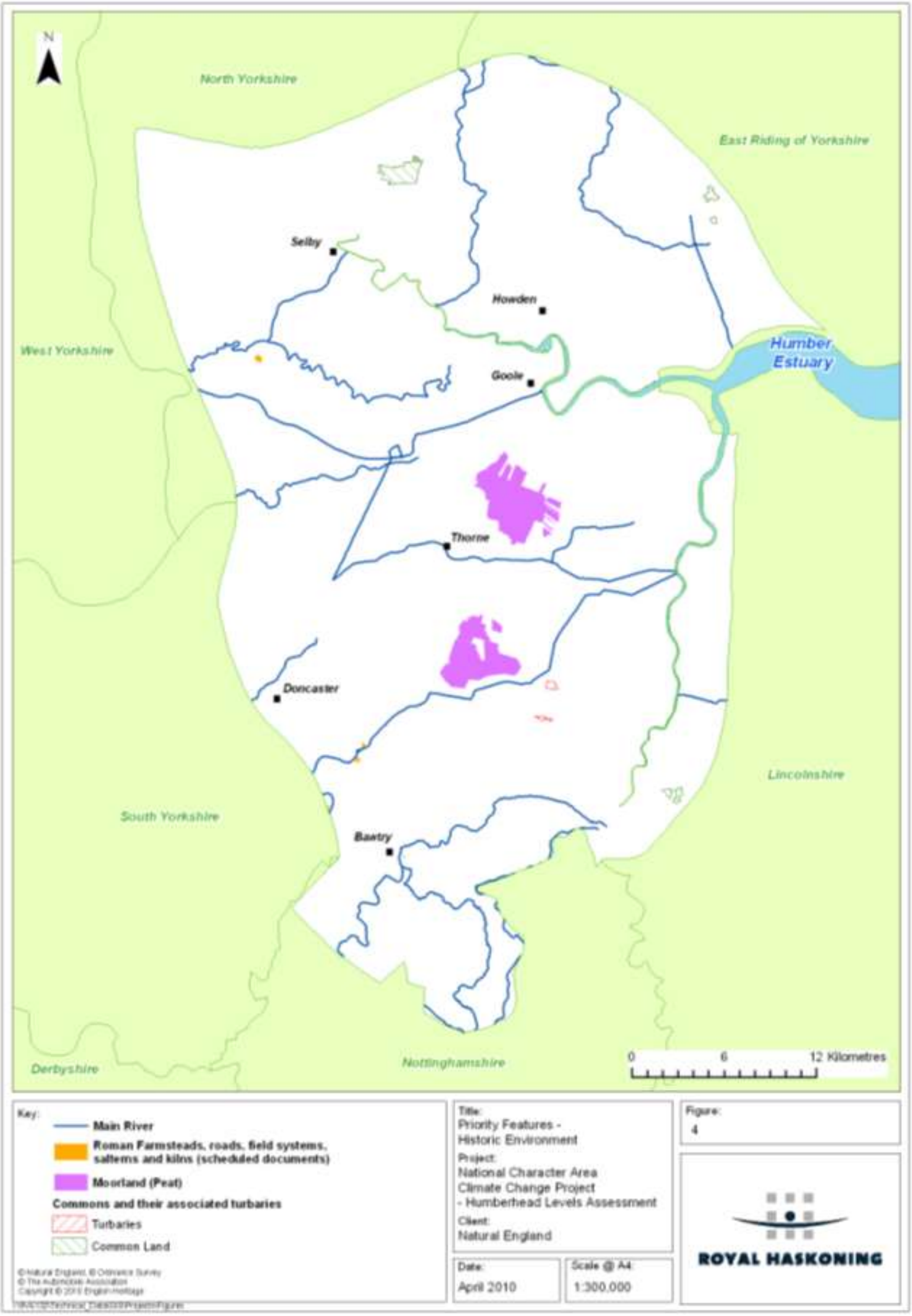

Figure 9 Priority features – historic environment

Biodiversity

4.48 The Humberhead Levels supports a wide range of species and habitats. These include habitats listed in the UK's Biodiversity Action Plan (UK BAP) and internationally and nationally important nature conservation designated sites. There are also a number of protected species to be found within the NCA.

Internationally important sites in the Humberhead Levels include:

- Lower Derwent Valley (Special Area of Conservation (SAC), Special Protection Area (SPA), Ramsar)
- Skipwith Common (SAC)
- Thorne Moor (SAC)
- Thorne and Hatfield Moors (SPA)
- Hatfield Moor (SAC)
- Humber Estuary (SPA, SAC and Ramsar)

Nationally important sites in the Humberhead Levels include:

- River Derwent
- Sandall Beat
- Potteric Carr
- Owston Hay Meadows
- Burr Closes
- Kirkby Wharfe
- Derwent Ings
- Skipwith Common
- South Cliffe Common
- Barn Hill Meadows
- Went Ings
- Thorne, Crowle and Goole Moors
- Crowle Borrow Pits
- Hatfield Chase Ditches
- Hatfield Moors
- Epworth Turbary
- Haxey Turbary
- Melbourne and Thornton Ings
- Tuetoes Hills
- Humber Estuary
- Laughton Common
- Scotton & Laughton Forest Ponds
- Misson Training Area
- Misson Line Bank
- River Idle Washlands
- Chesterfield Canal
- Barrow Hills Sandpit
- Haxey Grange Fen
- Shirley Pool
- Forlorn Hope Meadow

- Sherburn Willows
- Eastoft Meadow
- Sutton and Lound Gravel Pits

BAP habitats

There are ten UK BAP habitats within Humberhead Levels and a number of additional regionally important habitats. The key habitats in the NCA are discussed below and are illustrated in Figure 10.

4.49 **Lowland raised bogs** characteristically consist of a raised mound of peat above a water table which is fed only by rainfall (as opposed to ground water). This results in the development of surface vegetation which is adapted to acid, nutrient-poor conditions. Typical species found in this habitat include bog mosses, cotton-grass, sundew and bog rosemary. Thorne and Hatfield Moors are the most important areas of lowland raised bog in the Humberhead Levels and despite their long history of exploitation for horticultural peat they remain of international significance. As part of current management, drainage ditches have been blocked and water levels are being managed with a view to restoring vegetated peat surfaces and to regenerate the raised mire habitat. There is a significant amount of bare peat exposed which may take some time to be re-colonised[9].

4.50 **Reedbeds** are wetlands dominated by stands of common reed and are found in areas where the water table is at or above ground level for most of the year. These habitats usually incorporate areas of open water and ditch. Within the Humberhead Levels they are found at Broomfleet brick pits and washlands, Pocklington Canal, Melbourne and Thornton Ings, Skipwith Common, Potteric Carr, Bawtry Carr, River Idle near Everton Carr Farm, Gringley Pumping station, Isle of Axholme, Upper Humber estuary and Sutton and Lound Gravel Pits. Reedbeds are important habitats for birds including bittern, reed bunting, sedge warbler and reed warbler, as well as mammals such as water vole and otter.

4.51 **Fen, marsh and swamp** encompass a range of habitat types including vegetation that is fed by ground water or frequently inundated occurring on peat, peaty or mineral soils (UK BAP 2010a). Areas of fen habitat occur along the River Derwent and at sites such as Skipwith Common, Potteric Carr and Thorne and Hatfield Moors, with isolated fragments elsewhere. A number of priority species are associated with fen habitat, including invertebrates such as the mire pill beetle and plants such as great water parsnip.

4.52 **Wet woodland** occurs on poorly drained or seasonally waterlogged soils, often on floodplains around the margins of other wetland habitats, and is usually dominated by alder, birch and willow. The majority of this very scarce habitat, within the NCA, occurs on valley bottoms such as at Misson Carr SSSI.

4.53 **Running water.** There are many watercourses running across the NCA, including 17 main rivers such as the Derwent, Ouse, Aire, Went, Dearne, Idle and Trent. The river Derwent which flows south, across the northern boundary of the Character Area is a SSSI, designated for a range of interests including plants such as river water-dropwort and an exceptionally rich assemblage of invertebrates, including mayflies and eleven species of dragonfly. The river is also noted for its fish species and a diverse breeding bird community. The whole length of the river within the Character Area is designated a Special Area of Conservation, and the river and adjacent habitat in the Lower Derwent Valley are designated a Special Protection Area.

---

[9] Lowland raised bogs are valued in terms of their contribution to the UK's biodiversity as a whole. In themselves they are not as biodiverse as many other habitats. However, they are particularly interesting because of the specialist features found in such habitats

© Peter Roworth/Natural England

Plate 2 Water levels are managed and hare's-tail cotton grass established at Thorne moor

4.54 **Canals.** Reflecting the location of the NCA, between industrial towns and cities and their agricultural hinterland, the Humber ports and wider national and international markets beyond, the Humberhead Levels contains nine canals, of which Pocklington Canal on its northern boundary and Chesterfield Canal on its southern boundary are designated as SSSI. Both sites support important plant communities, and the former host 13 species of dragonflies and damsel flies.

4.55 **Flooded gravel pits and subsidence flashes.** Flooded gravel pits and subsidence flashes can provide an important habitat for plants and invertebrates. Although there are few such water bodies to be found in the Humberhead Levels, with sites such as at Thorpe Marsh relatively isolated, they are important resources for wildfowl and waders such as shelduck (Natural England, undated d). Mesotrophic lakes (which are relatively low in nutrients) are particularly valuable for wildlife and vulnerable to nutrient enrichment from fertilisers.

4.56 **Ditches** are extensive throughout the Humberhead Levels and provide a network of habitats for a range of species, including plants such as rare ferns and reptiles such as grass snake. Rare water invertebrates also thrive in ditches, including water snails and beetles.

4.57 **Coastal and flood plain grazing marsh** is a habitat of periodically inundated grasslands found within the flood plain of rivers and low lying coastal areas (Figure 10). Often cut for hay or grazed, a mosaic of grasslands, wetland marshes and ditches support plants, invertebrates and bird species such as lapwing, curlew, and more rarely corncrake (Selman *et al*., 1999). There are significant areas of this habitat along rivers such as the Derwent, Ouse and Don.

4.58 **Purple moor grass and rush pasture** habitats include a number of different species-rich fen meadow and rush pasture types, with plants such as purple moor grass and sharp-flowered rush usually abundant. Many sites have been lost to agricultural improvement (UK BAP 2010b). Within the NCA, these habitats continue to be found in isolated sites such as Epworth Turbary SSSI and Haxey Grange Fen SSSI in the south of the Character Area, and at South Cliffe Common SSSI near Holme on Spalding Moor in the north.

4.59 **Lowland heath** is characterised by the presence of ericaceous dwarf shrubs, such as heather, and is associated with areas of open water bogs, scattered trees and shrub, bare ground and acid grassland. It is predominantly found in areas below 300 metres above sea level and within the NCA the most important site is Skipwith Common.

4.60 **Lowland dry acid grassland** usually occurs on free-draining and nutrient poor soils over sands, gravels and acidic rocks. It is characterised by grass species such as sheep's fescue, tormentil, common bent and bristle bent. The habitat is particularly important for bird species such as nightjar and lapwing. Within the Character Area it is mainly found in an area between Bawtry and Doncaster, including within SSSI sites such as Epworth Turbary SSSI.

4.61 **Lowland deciduous woodland** includes most of the semi natural woodland types found in Eastern England. Although extensive in distribution, nationally there has been a significant decline in area over the last 50 years (UK BAP undated, b). Found in small patches most significantly in the south of the NCA, and often associated with conifer plantations and heath, it supports a number of UK BAP species.

4.62 **Hedgerows** can be an important habitat for a range of species, particularly in intensively farmed lowlands, as they may offer the only significant refuge for many farmland and woodland species which rely on them for food, shelter and dispersal. As wildlife corridors, they also link semi-natural habitats and help facilitate the movements of plants and animals throughout the countryside. As the Humberhead Levels is a relatively recently-drained landscape, it contains few hedgerows . Those that do exist are generally dominated by hawthorn, and are often neglected (restricting their potential as ecological corridors). Indeed, ditches might currently play a more important role as wildlife corridors than hedgerows. Field trees and hedgerows are often few and far between, although there is a higher density of hedgerows to the north of Doncaster where field boundaries take on a more enclosed feel.

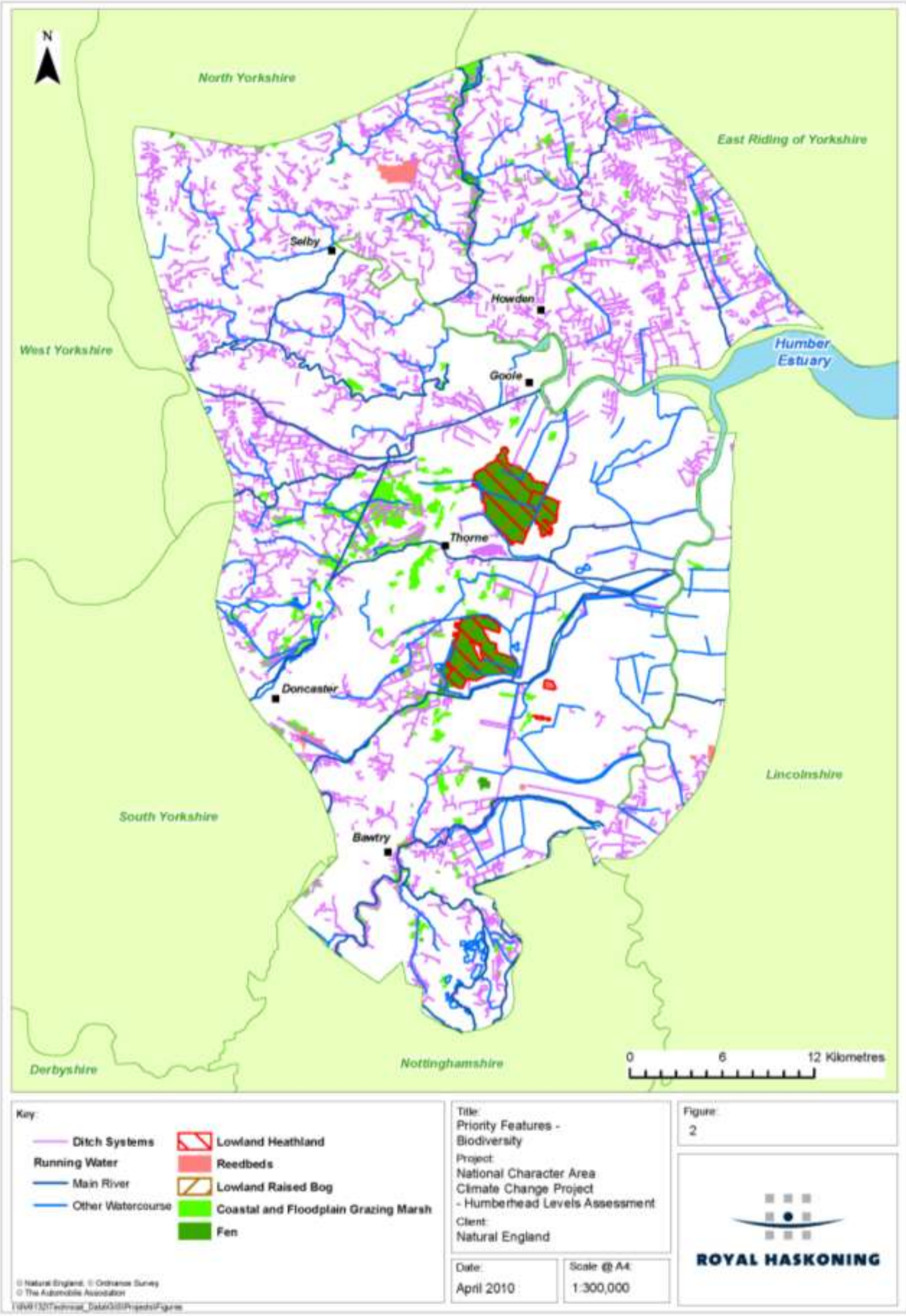

Figure 10 Location and distribution of key biodiversity features and watercourses

Key species

4.63 **Otters,** *Lutra lutra*, inhabit unpolluted water bodies such as rivers. Their diet mainly consists of fish, but they will also eat other foods such as frogs and crustaceans. Once widespread, populations declined due to pollution, hunting and habitat loss. However, the otter population is thought to be recovering well and recolonising parts of its former range (JNCC undated). Otter is a 'qualifying feature' of the Lower Derwent Valley SAC, though there are isolated records scattered along waterways throughout the Character Area (NBN undated, a).

4.64 **Bitterns,** *Botaurus stellaris*, occupy watercourses and lowland marshes and feed on fish and amphibians. The population is rare and localised with sporadic distribution in the Character Area.

4.65 **Common crane,** *Grus grus*. Since 2001 common cranes have bred, often successfully, at the Humberhead Peatlands National Nature Reserve. A large bird with a wingspan that can reach over seven feet, their numbers remain low nationally after returning to the UK in 1979, after having previously being considered extinct in the UK (Yorkshire Post, 29th August 2008).

4.66 **Marsh harrier,** *Circus aeruginosus*. The marsh harrier is the largest of the harrier species. Its preferred nesting location is reed beds, though it has been known to nest in cereal crops in the UK (Seago, undated). Populations exist in the Humber Estuary (NBN undated, b).

4.67 **Common darter,** *Sympetrum striolatu*. The common darter is a dragonfly whose habitat includes ponds and still water, though it may be see some distance from water. It is abundant in England, though its distribution is more localised outside of the south of England. The Character Area has a high density of records (NBN undated, c).

Plate 3 Common darter

Part 2 – Results of vulnerability assessment

4.68 This section summarises the assets in each category – habitat and species, geology and soils, historic environment, access and 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 1.

Habitats and species

More vulnerable

4.69 **Running water habitats,** such as rivers, canals and estuaries, are vulnerable to the higher winter flows that threaten to submerge bankside and in-channel habitat assets for more of the time. However, attempts to modify river channels to improve conveyance capacity may also cause the physical loss of riparian habitats. An increase in intense rainfall events may also cause increased run off into rivers, flooding and erosion, the effects of which may be increased sedimentation of river channels. However, the flat topography of much of the Humberhead Levels may mean that more significant loading will arise from upstream sources outside of the NCA. Increased nutrient loading as storms transport nutrients from land to the river may also cause eutrophication, not just in rivers, but in the ephemeral water bodies supplied by them (Clarke 2009). The floodplains of lowland rivers such as the Aire, Don and Trent will become more vulnerable to flooding (Environment Agency, a,b,c). There may also be some unexpected results of flooding events, such as the spreading of invasive species, such as Himalayan Balsam, between water bodies.

4.70 Just as wetter winters increase water flows in rivers, drier summers decrease them. Most at risk are the heads of streams and tributaries which may increasingly become ephemeral, leading to changes in habitat. The capacity of rivers to dilute pollutants will be reduced when water levels drop. This, combined with the lower dissolved oxygen levels in warmer rivers will put river ecosystems under stress (Clarke 2009). Where lower water levels combine with warm temperatures and high nutrients, eutrophication is more likely to occur. Canals may be particularly vulnerable to this impact.

4.71 Aquatic organisms are susceptible to thermal stress (Clarke 2009), which may mean that certain species may become more dependent on localised refuge or shelter areas or may migrate upstream to cooler, higher altitude rivers; though they may not find suitable conditions upstream, or may face barriers to getting there. Increases in water temperature may also alter the timings Large reaches of the major of migrations and the pattern of species that reside in particular river reaches. Large reaches of the lowland rivers of the Aire, Don and Ouse have sparse riparian and bank vegetation cover which will increase the vulnerability of bank erosion and increase in water temperatures meaning fewer refuge areas available for aquatic species.

4.72 **Lowland raised mires:** This habitat is particularly valuable in the Humberhead Levels and vulnerable to a range of the consequences of climate change. Changes in climate variables including wetter winters, drier summers and sea level rise may cause impacts such as fluvial flooding and coastal flooding, soil water deficit and increased risk of fire.

4.73 Flooding, for example, may increase the risk of 'bog burst', which is where an area of bog or peat shifts position (Scottish Executive, 2006), for instance in raised bogs the edges may slide away. Flooding can also cause large quantities of uncontrolled water to move around, redistributing or eroding the peat as it moves[10]. This can also lead to a range of indirect effects such as nutrient enrichment, which can change the species composition of the habitat.

4.74 Soil water deficit, as a result of drier summers, could compromise attempts at lowland raised mire restoration, and reduced rainfall during summer may make the established habitat unsustainable. Drying and oxidation of peat, followed by release of nutrients may alter species composition.

4.75 The water level regime is carefully managed in the Humberhead Peatlands through a system of cells and ditches to maintain wet bog and open water conditions and limit undesirable vegetation growth such as shrub and *Juncus* species. Changes in rainfall patterns could affect the management regime of water levels, which may need to be adapted to changes in the seasonality of rainfall, more favourable conditions for vegetation growth and increased fire risk. The bog habitat and underlying substrate could become more vulnerable to fire in long dry periods and this risk could be exacerbated by increased recreation or arson attacks, such as the Thorne Moor fires during a prolonged dry spell in 1995 and more recently during August 2010 (Natural England, 2010b).

4.76 **Coastal and floodplain grazing marsh** is another habitat that is vulnerable to climate change. Warmer summers, drier summers, wetter winters, the increased frequency of storms, and sea level rise may all affect this habitat. For instance, higher evapotranspiration as a result of warmer summers may result in changes to habitat composition and potentially the loss of breeding and feeding habitat for wetland birds. Coastal habitat is also vulnerable to sea level rise, particularly if its movement inland is constrained by hard features such as human flood defences (so-called ‘coastal squeeze’). The consequences could include saline intrusion and the loss of freshwater marsh species and botanical diversity if flooding occurs at the wrong time of year. However, wetter weather may make floodplain grazing marsh more widespread.

4.77 **Bittern:** More habitats for bittern may be created as wetter winters and a greater need for flood storage create new opportunities for fen habitats to form. However, sea level rise may affect bittern habitats negatively, particularly where storm surges affect coastal /estuarine sites resulting in coastal squeeze. Sea level rise over the coming 100 years could make storm surge events more likely to impact bittern populations in the Lower Derwent Valley SPA. Furthermore, the viability of bittern sites elsewhere in the Humber Estuary, and in their core population sites in eastern England, may be more at risk from such events. In prolonged dry periods, bittern habitat could also be vulnerable to drying out and nutrient enrichment. This could mean that suitable habitat outside of core sites becomes less likely to be occupied by bittern, as small populations outside of more south-easterly sites are unlikely to be acting as population cores from which young birds seek out new sites in which to breed (Gilbert *et al*., 2010).

4.78 Water quality may also affect bittern populations, particularly if it affects food supply levels of fish, eels, invertebrates or amphibians (Wigan Leisure and Culture Trust, undated). Increased runoff into bittern habitat could import pollutants leading to eutrophication and ultimately less prey availability.

[10] This is dependent on the condition of the peat if it is in good condition, ie if it is wet at the surface then soil/peat movements will be less. If the peat structure is in poor condition then it is more vulnerable to erosion / redistribution

Moderately vulnerable

4.79 **Lowland heathland:** A range of impacts from hotter summers, drier summers and wetter winters affect lowland heathland. For instance, warmer summers can lead to a longer growing season and changes in the species composition of this habitat, though soil water deficit in summer may reduce growth rates (Charman *et al.,* 2008)[11], so some uncertainty exists here. Areas of bare ground which are often important for invertebrate species, may decrease as plant growth rates increase during prevailing drier conditions, leading to declines in wetter microhabitats on site, affecting the populations of aquatic and semi aquatic species (Charman *et al.,* 2008). Heather beetle attacks may have a detrimental effect on heather, particularly if warmer winters combine with a wetter summer (though the UKCP09 projections suggest that drier summers are more likely). This habitat is also vulnerable to fire in drier summers and increased erosion rates may also occur as a result of a combination of drier summers and wetter winters. Skipwith Common, a lowland heath site, currently has a management regime of grazing and fencing to reduce scrub and purple moor grass, which is resulting in an improved heathland habitat.

4.80 **Carr woodland:** Hotter, drier summers may change ground flora communities in these woodlands, particularly rainfall dependent woodlands as they dry out in summer. Some woodlands may benefit from increased fluvial inundation.

4.81 **Deciduous woodland:** This habitat is likely to be vulnerable to an increase in intense rainfall events and fire risk. Pest species may also affect this habitat as climate changes. The distribution of deciduous woodland across the Humberhead Levels varies, with clusters of woodlands in the southwest, mid-west between Rivers Aire and Ouse and on the northern boundary, and more dispersed trees in the east. There are large areas of the NCA with no woodland habitat. This fragmentation might increase the vulnerability of woodlands and the species they support to some of the impacts of climate change.

4.82 **Hedgerows:** Hotter summers and warmer winters will lead to a longer growing season, which in turn may increasingly shade out herbaceous flora. In addition, the species composition of trees and shrubs in hedgerows may change as fewer frost events will mean less favourable temperatures for the regeneration of berry bearing species, which in turn will affect the food availability for wildlife. Many hedgerows are also associated with ditches, the vulnerability of which is described below. However, the wet ditch / hedgerow edge habitat may be particularly affected by reduced annual average rainfall and soil moisture deficit, as ditches are widespread in the Humberhead Levels. Intensive farming in large scale fields could reduce the resilience of hedgerows to climate change.

4.83 **Ditches** are widespread in the Humberhead Levels and may suffer from many of the same impacts of climate change as running water habitats, although ditches are likely to be worse affected, such as increased likelihood of eutrophication and toxic algal blooms. They may dry out for longer periods, and climatic conditions are likely to favour rapid vegetation growth and succession rates which will alter the habitat composition and increase shading. Hatfield Chase Ditches, a ditch system in the Humberhead Levels, currently suffers from poor water quality, vegetation structure and composition and therefore is likely to be particularly vulnerable to further stresses. Ditch networks behind flood embankments are likely to be increasingly impacted by flood events, introducing nutrients, salt, new species, and sediment.

4.84 **Fen habitats:** There is a variety of fen habitats of variable conditions in the Humberhead Levels. The composition of the ecological communities they support is likely to be changed as

[11] The additional phenomenon of carbon fertilisation may also complicate the picture, increasing the growth rate of plants, potentially favouring more competitive species, particularly if there are nutrient releases too, (Charman *et al.*, 2008).

a result of flooding and associated water pollution and of drying out. Because peat forms in fen habitats, the drying and oxidation of the peat layer can release nutrients into the water, changing species composition. If fen sites are lost, it is a difficult habitat to create elsewhere, especially those fen types which require a low nutrient status and particular ground water conditions to maintain their botanical diversity. Haxey Grange Fen in the Humberhead Levels is an example of a particularly vulnerable fen site, as it currently suffers from lack of management resulting in undesirable vegetation cover (prevailing soft rush dominance) and a water level that is prone to fluctuate.

4.85 **Reedbeds** will potentially be exposed to higher intensity rainfall and flooding. Though the vegetation is likely to be fairly resistant to this, associate species such as nesting birds may find themselves inundated. Drier summers may cause more frequent drying out of reedbeds and increased water temperature, which could lead to fish kills and the loss of species from these wetlands.

4.86 Table A and Table B (Appendix 1) summarises the results of the vulnerability assessment for habitats and iconic species.

Geology and soils

More vulnerable

4.87 **Peat:** Peat resources may be vulnerable to a range of changes in climate variables, including hotter and drier summers, wetter winters, sea level rise and increased frequency of storms. Drier summers could lead to a drying out of peat, and when this occurs peat may be lost through oxidation and erosion, exacerbating the peat loss that occurs through intensive cultivation (Gambolati *et al*., 2003; Kechavarzi *et al*., 2007). These same weather conditions could also increase the risk of fire, with consequent destructive effects on peat such as the late summer fire on Thorne Moor in 2010, although the peat habitat is showing signs that suggest recovery can expected within five years. Any further degradation or loss of peatlands would increase emissions of carbon dioxide to the atmosphere.

4.88 Peatlands are also vulnerable to erosion through uncontrolled water movement, which may occur as a result of flooding during wetter winters. Sea level rise and storm surges may cause coastal flooding and saline intrusion of sites. This could result in the inundation of low lying areas with some of our most valuable peat sites, such as Thorne and Hatfield Moors, being particularly vulnerable.

4.89 Other potential scenarios include the flooding of peatlands after periods of dessication leading to a sudden change in nutrient enrichment. Peat bogs are low nutrient input systems (McCorry and Renou, 2003) and an increase in nutrients could lead to increased vegetation growth damaging peat sequences.

4.90 In addition, peatlands in the Humberhead Levels could be affected by the way neighbouring land owners manage their land to reduce the impacts of flooding and the poorer water quality of floodwaters. If, for instance, additional drainage lowered water levels on a farm neighbouring a peatland, this could lower water levels on the peatland, exposing it further to the effects of drier summers. (For this reason, Environmental Stewardship agreements are currently in place that buffer the Humberhead Peatlands to help maintain water levels within the peatlands and minimise the effect of drainage from surrounding agricultural farmland.)

Moderately vulnerable

4.91 **Gravel pits and quarries** with exposed sandstone and gravels. A range of effects from climate variables, such as drier, hotter summers, increased frequency of storms and wetter winters, were identified as affecting these geological assets. For instance, increased vegetation growth resulting from a longer growing season may obscure geological assets, and cycles of drying and wetting of faces may lead to increased slumping. Wetter winters may lead to flooding and a consequent increased groundwater level may lead to the obscuring of gravel pits' geological interest features. An indirect effect of flooding may be pressure to fill sites in if they are perceived to have become dangerous. This habitat was further identified as being vulnerable to changing priorities of their use for either flooding or nature conservation.

4.92 **Loamy and clayey floodplain soils** with naturally high groundwater are vulnerable to water-logging of soils, flooding and erosion, all of which could affect the quality of these soils. Such processes may also increase the vulnerability of these soils to compaction as a result of mechanised operations, stock grazing or recreational use taking place in wetter conditions. A potentially positive effect of fluvial flooding may be an increase in sediment deposition on these soils, with a consequent beneficial effect on soil quality. More frequent storms may make soils unstable and prone to erosion from water or wind, particularly if climate change trends have encouraged changes in crop species that make soils more vulnerable to erosion.

4.93 Table C (Appendix 1) summarises the results of the vulnerability assessment for Geology and soil assets.

Historic environment

More vulnerable

4.94 **Palaeo-environmental records** in alleviated valleys may suffer from drying out and cracking of soils, which may damage sites and assets or cause loss of stratigraphic integrity, while soil erosion as a result of soil moisture deficit may destroy certain sites. One effect of drier weather is that deeper rooted plants are favoured. These can have a damaging effect on buried archaeology. Similarly changes in cropping patterns that result from climate change may have effects on these assets (English Heritage, 2004b). Changes in soil chemistry resulting from drought conditions may also affect remains (English Heritage, 2008a).

Moderately vulnerable

4.95 **Ancient trees:** More frequent storms could cause structural damage to ancient trees through high winds. Wetter and warmer winters could cause erosion and structural damage to assets, and may allow pest species to survive winters causing damage and decay to occur in buildings and historic plantings.

4.96 Sea level rise could submerge historic features near the Humber Estuary.

4.97 Table D (Appendix 1) summarises the results of the vulnerability assessment for historic environment assets. The table includes a sample of sites from a range of periods and features within the Humberhead Levels NCA.

Access and recreation

More vulnerable

4.98 **Waterways** could be affected by drought, high water levels, fluvial flooding and sea level rise. Lower water levels resulting from drought, in particular, might clearly reduce the opportunity for water based recreational activities and, as noted above, may help promote algal blooms, which can reduce amenity value. Drought conditions in 2010 forced a canal elsewhere in Yorkshire to close to conserve water supplies and wildlife (The Independent, 13 July 2010). Wetter winters and more frequent storms may affect the recreational value of waterways, making certain water based activities more challenging and causing bank erosion and potential deterioration or loss of riparian access. For example, the summer 2007 floods caused extensive towpath damage along the Aire & Calder navigation in a NCA close to the Humberhead Levels (Transpennine Trail, 2011). Sea level rise may, through high tidal reach and coastal flooding, cause the loss of some existing waterways.

4.99 **Rights of way:** Parts of the rights of way network, including cycleways, may be affected by sea level rise. Hotter drier summers may attract more people out to the rights of way network. High numbers of users will bring with them greater path surface erosion and path edge erosion. A longer growing season may also cause some path edges to become overgrown, potentially causing some parts of the network to become impassable.

4.100 Erosion may also occur as a result of wetter winters and more frequent storms, and some routes could be lost or damaged by flood water. More intense storms could affect key infrastructure in the access network, such as bridges.

Moderately vulnerable

4.101 **Open access land** may be vulnerable to a lesser extent than other recreational assets. However, as much of the Character Area's open access land is in the peatlands, which are vulnerable to a range of erosion and wildfire impacts (see the habitats section), an indirect effect of such factors may be a limiting of access if a site's conservation value is felt to be threatened. A range of other access assets, such as Local Nature Reserves, Wildlife Trust sites, woodlands, urban green space, permissive routes and routes along estuary flood banks are also vulnerable to increased recreational pressure which may result from a warmer climate. Designated and important features within these sites may suffer climate related impacts which could diminish their access and educational value if features are damaged or lost.

4.102 Generally, warmer weather throughout the year appears likely to attract more people to the NCA's outdoor recreational resources, with a range of positive effects on health and the local economy. While in some places opportunities will be lost as a result of the potential damage to the access network described above, there is likely to be an increase in demand for outdoor recreation.

4.103 Table E (Appendix 1) summarises the results of the vulnerability assessment for access and recreation assets.

Other key elements of landscape form

More vulnerable

4.104 'Productive land in large scale and geometric field patterns' is a difficult asset to assess. While the overall pattern of the landscape is unlikely to change, changes in the crops grown within the landscape may radically change the texture of the landscape. While the climate itself may make the landscape more productive for plants such as sunflowers, it will also drive demand for biomass crops. It may also change the timing of crop planting, with more potential for taking two crops per year. This will inevitably change the look of the landscape. It may also, as discussed in the soils section, affect erosion rates, soil moisture deficit and water logging, particularly in wetter conditions.

4.105 At the same time, historic landscapes are vulnerable to impacts from new cropping regimes. Historic field patterns are an example of a vulnerable element. Drier summers may favour conversion of pasture to arable in some fields containing ridge and furrow, resulting in gradual ploughing out of the feature. Similarly, smaller more enclosed landscapes may be changed if the taking of two crops per year makes it viable to remove hedgerows and create larger arable fields. Taller crops, such as certain biomass crops, may obscure field boundaries in vistas across the landscape.

4.106 Table F (Appendix 1) summarises the results of the vulnerability assessment for other key elements of landscape form.

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

4.107 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’. Possible adaptation options are suggested for each set of changes.

4.108 (A full list of potential changes to each individual element of landscape character, ecosystem services biodiversity is included in Appendix 2, and adaptation options for each element in Appendix 3.)

Agricultural land and the broad floodplain

4.109 While the underlying geomorphology that gives the NCA its low lying character is unlikely to be greatly affected by climate change, land use is likely to change in response to changes in temperature and precipitation and their consequences, such as waterlogging, compaction and erosion of soils, and longer growing seasons. Changes in agricultural and other land use could be the factor that has the greatest effect on the landscape character of the Humberhead Levels. Although the large geometric field boundaries are unlikely to change significantly, new crops and, potentially, new built structures such as wind turbines could alter landscape character and the ‘sense of place’ it provides.

4.110 Potential adaptation actions to address the vulnerability of agricultural areas in the NCA include:

- Retain and maintain water level management engineering assets such as ditches where they protect a proportion of the best and most versatile land and do not compromise wider environmental goals, for example, by taking a phased approach to clearing of ditches, or by clearing one side at a time.
- Encourage good land management practice which helps to help retain and improve soil structure, water retention capacity (where appropriate) and reduce erosion.
- Target appropriate Environmental Stewardship options to help protect key historic environment assets associated with agriculture, for example, strip farming on the Isle of Axholme.
- Carry out research into hedgerow management, including the provenance of hedgerow species.
- Carry out research into appropriate new crops to provide better information and guidance to farmers in the NCA.
- Monitor pests, diseases and pollinator populations.
- Promote greater on-farm water storage, sensitive to landscape character.
- Where environmental constraints allow, direct biomass fuel production to poor quality land (excluding wetlands).
- Invest in low-water demanding technologies, including more drought resistant crops.

Rivers and wetlands

4.111 As noted above, the wetland habitats and palaeo-environmental deposits associated with the rivers of the Humberhead Levels are likely to be vulnerable to seasonal changes in flows. This could lead to a change in the matrix of important freshwater ecosystems that support much of the area’s wildlife and provide important ecosystem services. The response of people to climate change could further increase the vulnerability of riparian habitats and buried archaeology if attempts to modify river channels result in habitat loss. The flood storage function performed by floodplains and wetland habitats is likely to become more significant as winters become wetter and there are more intense rainfall events. Wetter winters may challenge the capacity of floodplains to store water as they are likely to receive higher water volumes. However, if floodplains are inundated more regularly, there may be benefits for biodiversity and buried archaeology.

4.112 Potential adaptation actions for wetlands, open water habitats and floodplains in the NCA, including opportunities to enhance ecosystem service benefits, include:

- Measure and monitor all elements of the historic environment in the floodplains to enable a prioritised response.
- Where possible work with landowners to encourage entry into land management agreements sympathetic to the need to conserve historic environment assets in the floodplain through environmental stewardship schemes.
- Increase the capacity of the catchment to retain rainfall runoff and slow flows through ‘naturalisation’, and investigate the need for more strategic management including upstream water storage activity where consistent with landscape character.
- Target Higher Level Stewardship at wetland and open water habitats to facilitate best practice management.
- Extend the area of land managed as water dependant habitats by raising water levels where appropriate, for example flood meadows or salt marsh. Create more open water pools as part of sustainable drainage schemes and in the management of washlands and flood meadows.
- Manage washlands and water bodies to increase structural diversity, for example, a variety of ground levels, which will help to retain winter flood water for longer and provide refuges for species vulnerable to inundation events.
- Increase ecosystem resilience by buffering water bodies from ingress of pollutants and sediments and promote management of non-native species.
- Consider the extension of SSSI / RIGS boundaries where gravel pits of geological interest become flooded, and ensure that management plans for gravel pits maintain geological interest assets where possible.
- Ensure licensing regimes effectively regulate water abstractions at a sustainable level.
- Promote demand management and water conservation.
- Restore riparian shading in places to reduce effects of heat stress on aquatic organisms, particularly on lowland rivers of the Aire, Don, Ouse, Idle and Torne and exposed areas of canals.
- Increase the connectivity / permeability between freshwater wetlands and open water habitats across the landscape.
- Reduce sources of external stress to allow development of healthier habitats more able to cope with additional stresses imposed by climate change. Work with landowners adjacent to important wildlife site to ensure that pollutant input and disruption of hydrological regime is minimised.

Estuarine wetlands

4.113 The vulnerability of estuarine wetlands in the upper part of the Humber estuary and its tributaries to sea level rise and coastal erosion could have a number of consequences. The area of estuarine habitats in the landscape could be reduced as a result of coastal squeeze, and areas currently covered by freshwater habitats could shift to more saline communities, resulting in significant changes in and possibly losses of biodiversity. Important species such as the bittern could be affected by changes in this area. Any reduction in the area of semi-natural habitat in these estuarine areas could result in a reduction of the flood alleviation service, increasing the vulnerability of inland areas to tidal flooding. Sea level rise and an increase in tidal flooding could also lead to the loss of historical assets close to the Humber

Estuary. If these historic features are lost, they cannot be replaced. The effects of climate change in this part of the Humberhead levels may not all be negative, however. If climate change leads to increased demand for managed realignment of the estuary as a flood defence strategy (as has been successfully implemented at Alkborough, on the estuary just to the west of the Humberhead Levels NCA; Natural England 2009e), significant biodiversity and flood alleviation benefits could be achieved.

4.114 Adaptation actions to address the vulnerability of areas near the Humber estuary coast to the impacts of climate change include:

- Where suitable, expand intertidal habitats around the Humber Estuary to offset coastal squeeze and increase sustainability of flood defences elsewhere.
- Increase the connectivity / permeability between estuarine habitats across the landscape;
- Measure and monitor all elements of the historic environment at the coast to enable a prioritised response.

Peatlands

4.115 The vulnerability of the Humberhead Levels' important lowland peatlands to drying out and fire as a result of drier summers and water-logging in winter could degrade the underlying peat soils and change species composition. Pressures resulting from climate change may reverse the recent improvements in habitat quality made at iconic sites such as Thorne and Hatfield Moors. In addition to implications for biodiversity, loss of peat soils and habitats could result in the release of significant amounts of carbon. The valuable buried archaeology and the pollen record contained in these peatlands could also be damaged.

4.116 Extreme events such as fires have the potential to alter the appearance of the landscape over very short time-scales and may restrict recreation in peat areas.

4.117 Adaptation actions to address the vulnerability of peatlands include:

- Increase the resilience of peat habitats by working with stakeholders to reduce negative impacts of land use adjacent to bogs, for example, by creating buffer strips around bogs.
- Create wetland habitats adjacent to bogs.
- Maintain and enhance good water control measures at sites to maintain water levels and protect palaeo-environmental evidence.
- Ensure appropriate weight is given to rarity and status of peat bogs and raised mire habitat in flood management plans for the Humber.
- Develop emergency response plans to reduce fire risk and incorporate visitor management strategies where necessary.
- Continue to undertake bog restoration activity, particularly at Thorne and Hatfield Moors, extending good practice to other sites.
- Measure and monitor elements of the historic environment in peat areas vulnerable to climate change to enable a prioritised response.
- Where possible, work with landowners to encourage entry into sympathetic land management agreements through environmental stewardship schemes.
- Enhance 'permeability' of the landscape between key sites so individuals can move between populations.

Access and recreation opportunities

4.118 Warmer summers may encourage people to use the outdoors more for recreation. This may put pressure on existing recreation facilities such as footpaths and country parks. Recreation facilities could also be directly affected by the consequences of climate change, such as footpath erosion and drying out of grassed areas. The challenge will be to maximise the opportunities for increased access to and enjoyment of the natural environment while maintaining and enhancing the necessary facilities.

4.119 Adaptation actions to manage access and recreation assets in the NCA and take advantage of opportunities include:

- Greater and enhanced maintenance regime and higher construction standards for pathways.
- Educate countryside users about sensible use, such as bringing water on walks and how to reduce fire risk.
- Incorporate visitor management strategies on key sites where necessary.
- Prioritise maintenance of rights of way and accessible green space close to settlements.
- Seek opportunities to increase provision of green space provision to accommodate increasing recreational demand.
- Identify sites which are likely to become more popular for recreation and assess and develop their infrastructure to cope with increased user numbers.

Strategic actions

4.120 A number of strategic actions were identified which could provide an overarching framework for delivering adaptation within the Humberhead Levels and support the more specific actions above.

4.121 There needs to be a focus on **catchment scale adaptation** beyond the boundary of the NCA. Such an approach should look to implementing measures in the head waters of the main rivers within the Humberhead Levels to support integrated water management and reduce flood risks. While River Basin Management Plans do this to a degree, decisions need to be made at a catchment level on areas where it might be beneficial to allow flooding and to target measures to reduce surface run off and nutrient input from farmland. Further work is required to look at opportunities for capturing peak river flows in the floodplains that can be stored and used for water supply at times of peak demand (low rainfall).

4.122 We need to take a **large-scale approach** to managing and creating habitat. As the climate changes, it will be important that species have the ability to shift. This will require looking at the landscape as a whole, and taking advantage of the many microclimates, soil conditions and aspects that exist at this scale to ensure that patches of semi-natural vegetation and species populations are not isolated from each other and that the way the landscape is managed as a whole provides a coherent ecological network that facilitates species movement between a range of sites.

4.123 **A consideration of climate change adaptation should be built into the spatial planning agenda.** There are real opportunities to build climate change adaptation into the local planning framework. Green infrastructure has a particularly important role to play in supporting community resilience while delivering wider biodiversity and landscape benefits and needs to be central to the development of Local Development Frameworks. As part of this approach the existing or potential functionality of land allocations should be considered in terms of their ability to support climate change adaptation while also enhancing biodiversity within the NCA, and tools such as sustainability appraisal should ensure that the impacts of development (for example, water extraction) do not exacerbate the impacts of climate change on the natural environment.

4.124 **Development of multi-functional wetlands.** There are opportunities to develop the network of wetlands through managed realignment to provide water storage, reducing the risk of flooding while at the same time enhancing biodiversity and amenity value.

4.125 **Understanding and responding to land use change.** It is anticipated that farming in the Humberhead Levels could undergo radical change in the coming decades. It will be important to work with land managers and farmers to anticipate changes and develop appropriate responses. The next round of Higher Level Stewardship agreements have the potential to assist in the delivery of climate change adaptation, focusing on the value of wetlands, flood storage, carbon sequestration and green infrastructure, as well as supporting farmers seeking to improve the resilience of their businesses. However, even simple measures taken through Entry Level Stewardship, such as the creation of field margins next to rivers and ditches can help overcome the increasing threat of polluted water arising through climate change or provide additional habitat and feeding areas.

4.126 **Build partnerships** to manage the land around key assets. Sites such as the Humber Peatlands are vulnerable to outside influences such as land drainage beyond their boundaries or fire risk as a result of vandalism. Site managers, planners, public services and community groups need to work together to promote adaptive response to climate change that benefit all parties.

4.127 There is a need to increase **public awareness and understanding** of the potential impacts of climate change. Decision-makers, and landowners and farmers have a key role in developing appropriate policies and taking action.

4.128 **Monitoring** change and the effectiveness of adaptation measures is critical to an adaptive management approach. Further work is needed to continue to map and research the vulnerability of natural assets to climate change as knowledge is still incomplete. Long term data sets and studies assessing environmental change will also be very important to inform adaptive management. Critical areas for monitoring will include habitat and species monitoring, hydrological regime and water quality monitoring, monitoring the condition of historical sites and geological assets and monitoring landscape change.

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, biodiversity and ecosystem services in the Humberhead Levels NCA. It may also present some opportunities. Some of the most vulnerable elements of landscape character identified in this study were wetland assets such as ‘peat bogs and raised mires’, ‘ponds and flooded gravel pits’, ‘ditches, canals and altered river courses’ and ‘coastal and floodplain grazing marsh’. Some drier assets such as remnant heath and palaeo-environmental deposits are also vulnerable.

5.2 As noted above, the cumulative effects of the vulnerability of these and other important natural assets in the Humberhead Levels, to both direct and indirect (human-mediated) effects of climate change, seem to indicate potential major changes to landscape character, ecosystem services and/or biodiversity in five particular areas or categories: agricultural land and the character of the broad floodplain; rivers and wetlands; estuarine wetlands near the Humber estuary; the area’s important lowland peatlands; and access and recreation. Too much or too little water, and the need to manage it, was a theme that ran throughout many of the conclusions.

5.3 Below, we discuss some aspects of the vulnerability results in more detail.

5.4 This report considered the vulnerability of the major ecosystem types in the Humberhead Levels in some detail. Amongst the habitats assessed as vulnerable to climate change were running water, lowland raised mire, and coastal and floodplain grazing marsh. Periods of drought were seen as particularly threatening to these habitats, but other impacts of climate change such as wetter winter weather may bring a range of other impacts, particularly where run-off increases nutrient loading.

5.5 Recent work examining the vulnerability of habitats across England, based on habitat extent, exposure to climate change and adaptive capacity (Catchpole, 2010) quantifies adaptive capacity at a 1 km^2 resolution according to the extent of ecological networks defined in the England Habitat Network 2.0, variation in elevation within the unit, the number of soil types and land cover dominance. This is based on the assumption that areas of high adaptive capacity ‘will enable more species to persist in the future because a greater range of microclimates and environmental conditions will be available’ (Catchpole 2010). From this perspective, factors working against adaptive capacity in the Humberhead Levels include the low degree of variation in elevation, large tracts of arable farmland, and a general fragmentation of habitat patches in many areas. The results of Catchpole’s work show a number of BAP habitats in the Humberhead Levels appear highly vulnerable.

5.6 This report has highlighted that the species that depend on the habitats within the Humberhead Levels are also vulnerable to climate change. A number of iconic species were identified, with some species, such as otter and bittern, clearly dependent on freshwater habitats which are vulnerable to the effects of climate change. For some other species it was harder to predict the effects of climate change. For example, some marsh harriers already make use of farmland rather than their traditional reed bed habitat for nesting and feeding. This indicates some potential for an adaptive response to climate change. Climate change impacts are not just confined to these headline species, however. For instance, species populations currently at their southern limit may be particularly vulnerable to climate change (Charman *et al*., 2008). At Thorne and Hatfield Moors, for example, there are a number of species that are at the southern edge of their range, including bog rosemary *Andromeda* *polifolia* and the large heath butterfly *Coenonympha tullia*. Such species might require additional management to enable populations to persist in the area.

5.7 Several habitats were assessed as being exposed to conditions that may initiate changes in community composition. This is a complex area as there are a number of variables that affect plant growth. Factors such as the distribution of temperature change, number of frost free days, frost dates, evapotranspiration rates and soil moisture all affect growth of bracken, for example (Pakeman and Marrs 2010), while atmospheric carbon and nutrient availability also affect growth. Many of the habitats in this study are exposed to climate trends that will encourage more plant growth, but lower soil moisture and evapotranspiration rates may suppress plant growth during the warmer drier periods (Pakeman and Marrs, 1996). While the effect on overall biomass is unclear, it is likely that some species will be favoured by changed conditions and could out compete less well-adapted plant species. For bracken, at least, biomass levels were predicted to change slightly at a rate of 0 to 15 percent for the northern part of the Humberhead Levels (Pakeman and Marrs, 1996), which may warrant monitoring at heathland sites for instance.

5.8 Several of these habitats, such as lowland raised mire, not only support important species but also contribute to key aspects of landscape character. Thorne and Hatfield Moors constitute the largest areas of this habitat type in Britain, albeit suffering from a history of degradation due to peat extraction. Further degradation of this asset as a result of the climate change impacts identified in this study could lead to a significant change in the area's overall character as well as some of the ecosystem services it provides.

5.9 Similarly, water bodies such as rivers, aside from being important habitats in their own right, contribute to several of the ecosystem services of the Humberhead Levels, such as freshwater provision, drainage and recreation, and to landscape character. It is, therefore, important to recognise that the value of habitats such as these extends beyond their intrinsic value for wildlife, and loss or degradation of these assets has wider implications for the benefits the area provides to people. Impacts such as eutrophication and pollutant loading from the combined impacts of runoff and drier spells could lead to these water assets becoming less biodiverse, less able to supply freshwater, and less able to contribute to the aesthetic qualities of the Character Area.

5.10 For geology, the concern is often the continued visibility of geological exposures, which are clearly vulnerable to impacts such as increased vegetation growth or being covered by water. For soils, which are crucial for delivering food and biomass production, the impacts are more diverse. Erosion, compaction, desiccation, flooding and, in some cases, salinisation, may all impact on the productivity of soils to varying degrees, depending on soil type. However, often the type of farming that takes place will either amplify or reduce these effects. For instance, the types of crops planted as a reaction to warmer weather or a longer growing season may induce varying erosion rates (SOWAP 2007), which may combine with higher rain intensity and run-off to result in an amplified rate of erosion. This illustrates the potential significance of human-mediated indirect effects of climate change.

5.11 Changes to farming practices are potentially one of the most important human-mediated effects of climate change identified in the study. Another risk is the potential effect of changes to land management adjacent to lowland raised mire sites. This could affect water supply to the habitat, leading to a range of impacts, such as desiccation of peat and loss of carbon. However, it should be noted that while human actions have great potential to exacerbate the vulnerability of the natural environment, there is also great potential for land management that is sympathetic to the environment and achieves benefits for both people and wildlife. Using the network of river floodplains to regulate flooding is one example.

5.12 It should be noted that some climatic changes have highly uncertain impacts and in some cases a range of potential possible positive and negative changes were identified. For example, there could be increased opportunities for outdoor recreation at the same time as damage to walking paths. Increased flooding of certain areas could create threats for some species and opportunities for others. Changes in one place or at one time of year, such as stress on fen ecosystems and the species they support during drier summers, could be compensated by changes elsewhere or at other times, such as wetter winters raising the water table and allowing new fen habitat to become established. This illustrates the need to be prepared for a range of potential changes and consequences.

5.13 This study identified a number of strategic actions to increase resilience to climate change, and then identified a number of more specific adaptation actions relevant to individual landscape characteristics, ecosystem services and aspects of biodiversity. What was clear from this assessment was that many of the actions proposed were indeed ‘win- win’ and ‘low regrets’ actions, and would be likely to have a range of benefits. For example, the strategic action of developing multifunctional wetlands would not only make a positive contribution to the resilience of biodiversity, it would also contribute to enhancing access and recreation opportunities by creating more places where people can participate in activities such as walking and bird watching. It would also contribute to the delivery of ecosystems services (for instance by providing flood water storage) and to landscape character.

5.14 Similarly, more specific actions aimed at preserving key landscape characteristics or ecosystem services, more often than not, exhibited multiple benefits that would help increase broad resilience to climate change. For instance, working with landowners to reduce the negative impacts on hydrology that their activity may have on peat bogs and raised mires would help to maintain a nationally important area of lowland peatland ecosystems, maintain carbon stored in peat soils, preserve the archaeological record these areas contain, and enhance the attractiveness to visitors of areas such as Thorne and Hatfield Moors as ‘wild’ areas in an otherwise heavily farmed landscape.

5.15 In some cases, adaptive actions were able to be refined to make them more multifunctional in nature once their range of additional impacts was identified through the matrix developed for this project. Thus, use of such a matrix enabled ameliorating measures to be incorporated where adaptive measures potentially conflict with other priorities.

5.16 Some adaptive actions occurred repeatedly throughout part 3 of the report. This might suggest that economies of scale might be achieved through prioritising such actions. These recurring adaptive actions included:

- Monitoring change in key environmental assets.
- Targeting Environmental Stewardship to increase the resilience of assets.
- Increasing the water storage capacity of river catchments, or introducing managed re-alignment schemes in estuarine areas.
- Reducing fire risk and developing emergency response plans for key locations.
- Managing soils better to reduce water demand, run off and erosion.
- Increasing habitat connectivity / making the landscape more ‘permeable’ to wildlife.
- Reducing pest and disease threats.
- Undertaking adaptive management and increasing the habitat diversity of wildlife sites.
- Retaining water management assets and on farm water storage.
- Managing visitors to the countryside.
- Slowing the spread of non-native species.

5.17 It should also be noted that many adaptation responses are not only multifunctional, but may play an important role in addressing climate change itself. For instance, protecting peat bogs allows that habitat to continue to absorb carbon dioxide. Soil conservation measures in agriculture can also play a role in sequestering carbon dioxide (Farming Futures 2008). This type of positive feedback should be recognised by policy makers and conservation and land mangers looking to reduce emissions of greenhouse gases.

Limitations of the study and areas for further work

5.18 While this study should provide as a useful starting point to pursuing adaptive responses to climate change in the Humberhead Levels, a number of limitations should be recognised.

5.19 One issue relates to the scale at which vulnerability and adaptation should be considered. In order to consider a wide range of natural assets in a reasonably large area of land, this study necessarily took quite a broad and general approach. This meant that is was not possible to look in detail at specific locations within the study area. Nor was the biodiversity aspect of the study able to look in any detail at how individual species might be affected by climate change, beyond considering a few iconic species in the area. Instead, it focused on general ecosystem types. This enabled a broad picture of how changes to habitats, particularly abiotic elements such as soil and water, might affect species, but did not enable a detailed assessment of how particular ecological communities might change, nor of how the vulnerability of particular species might vary across the study area.

5.20 At the opposite end of the scale, some aspects, particularly those relating to river systems and hydrology, require consideration across an area larger than the study area. While many actions, such as buffering watercourses and re-naturalising catchments can occur within the Humberhead Levels, some actions might be required in the rivers upstream, or in the Humber estuary downstream. In particular, reducing water input during peak flows, and ensuring flow is moderated over a longer period relies on working at a catchment scale. Further work on a similar methodological basis may be required in other parts of the key catchments in the area in order to provide a comprehensive evidence base for action at this scale.

5.21 At this large scale, the study could also have been improved by taking a more spatially-explicit approach to considering the current ecological networks within the area and surrounding NCAs, evaluating their resilience and ability to facilitate species responses to climate change.

5.22 A further limitation of the study arises from its reliance on the opinions of experts and workshop attendees. While a range of experts contributed to the study, there was inevitably a greater amount of information available on some topics than on others. While this study has tried to supplement expert opinion with external references wherever possible, there are assets in the Character Area whose vulnerability to climate change is less well-understood and it is possible that vulnerability scores could have been under-estimated for some assets, in some places, as a result. Further ongoing research will help fill these gaps, and in the meantime it should not be assumed that natural assets assessed as being 'less vulnerable' will not require adaptation management. Appendix 5 shows the organisations that attended workshops. This gives some indication of where gaps in the evidence base used by the study may lie.

5.23 Aside from these limitations, the findings presented should provide a useful starting point to focus the work being undertaken throughout the Humberhead Levels to adapt to climate change. It also reaffirmed some widely acknowledged principles, such as those described by Hopkins *et al*., (2007), and explored how these principles could be applied to this specific Natural Character Area.

5.24 We suggest that the following steps should ideally be taken following this vulnerability assessment, both to extend and built on the results and to start to implement some of the recommendations:

- Further assessment of the vulnerability and possible adaptive actions could usefully be undertaken for assets in smaller local areas within the Humberhead Levels, using this broad vulnerability assessment as a guiding framework. This should include considering the vulnerability and likely responses to climate change of a much wider range of individual species.

- As noted above, a study should also be done of vulnerability of the river systems in the area, and possible adaptation measures to be taken, at a catchment scale.
- More detailed work should be done on ecological networks around the Humber estuary and its tributaries, building on information and maps in Lawton *et al.,* (2010) and Catchpole (2010).
- It will be necessary to consider the most appropriate geographical unit(s) within which to implement adaptation actions, taking into consideration the seven Local Authority areas that overlap the NCA, hydrological units and spatial distribution of the natural assets identified in this study.
- Adaptation actions will also need to be explored in further detail, in partnership with interested stakeholders in the area such as the Humberhead Levels Partnership. Detailed planning should discuss the implications for future delivery, and to consider how to maximise benefits and minimise the downsides of adaptation actions. It is clear that partnership approaches will be needed for adaptation actions to be implemented successfully.

Conclusion

5.25 The study provides a systematic assessment of the valued assets and functions of the natural environment of the Humberhead Levels and how they might be vulnerable to climate change. By adopting an integrated approach in a specific location, this study and its sister studies have been able to identify a wide range of potential climate impacts on the natural environment and to examine how these might vary in different parts of the country. The approach has also enabled the studies 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 particular landscape and the benefits and services it delivers.

5.26 It is hoped that the findings of this study of climate change vulnerabilities and adaptation will 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 Humberhead Levels 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 area, and that it will help support future partnership working, as many of the proposed adaptation measures cut across responsibilities and local authority boundaries.

6 References

BATJES, N.H. 1996. Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science*, 47, 151–63.

BIRD GUIDES, undated. Common Crane: Grus grus URL: **www.birdguides.com/species/species.asp?sp=039001** [Accessed June 2013].

BRADY, N. and WEIL, R. 2008. The Nature and Properties of Soils. 13th Ed. Prentice Hall.

CATCHPOLE, R. 2010. National Climate Change Vulnerability Assessment: Technical Information Note. Natural England (unpublished Natural England internal document).

CHARMAN, D., LAINE, J., MINAYEVA, T., SIRIN, A. 2008. Impacts of Future Climate Change on Peatland; in PARISH F., SIRIN, A. CHARMAN, D., JOOSTEN, H., MINAYEVA, T., SILVIUS, M. and STRINGER, L., (eds). Assessment on Peatlands, Biodiversity and Climate Change: Main Report. Global Environment Centre, Kuala Lumpur and Wetlands International, Wageningen.

CLARKE S.J. 2009. Adapting to climate change: implications for freshwater biodiversity and management in the UK. *Freshwater Reviews* 2, 51-64.

CONLAN, K., LANE, S., ORMEROD, S. and WADE, T. 2007. Preparing for climate change impacts on freshwater ecosystems, PRINCE: result, Environment Agency Science Report SC030300/SR. Bristol, UK.

COOMBES, E., JONES, A.P., HILLSDON, M. 2010. The Relationship of Physical Activity and Overweight to Objectively Measured Green Space Accessibility and Use. Social Science and Medicine, vol 70, Issue 6, March 2010, pp816-822.

COUNTRYSIDE AGENCY (now Natural England). 2002. Landscape Character Assessment: Guidance for England and Scotland. The Countryside Agency, Cheltenham.

COUNTRYSIDE COMMISSION. 1998. Countryside Character: Yorkshire & Humber, The Character of England's natural and man-made landscape, Volume 3, Character area 39, Humberhead Levels. Pg 101-106 URL: **www.naturalengland.org.uk/ourwork/landscape/englands/character/areas/humberhead_levels.aspx** [Accessed June 2013].

COUNTRYSIDE QUALITY COUNTS. 2007. Tracking Change in the Character of the English Landscape: 2nd Assessment. URL: **http://webarchive.nationalarchives.gov.uk/20101219012433/http://countryside-quality-counts.org.uk/pubs_2ndAssess.html** [Accessed June 2013].

DOWNING, T.E., & PATWARDHAN, A. 2005. Assessing Vulnerability for Climate Adaptation. In: B.LIM & E. SPANGER-SIEGFRIED, eds. *Adaptation Policy Frameworks for Climate Change:Developing Strategies, Policies and Measures*, 67 – 89. Cambridge: Cambridge University Press.

ENGLISH HERITAGE. 2004a. Flooding and Historical Buildings: Technical Advice Note.

ENGLISH HERITAGE. 2004b. Farming the Historic Environment: Caring for archaeological sites on arable land.

ENGLISH HERITAGE. 2008a. Climate Change and the Historic Environment.

ENGLISH HERITAGE. 2008b. Conservation Bulletin, Issue 57.

ENVIRONMENT AGENCY. 2010a. Aire Catchment Flood Management Plan, URL: **http://publications.environment-agency.gov.uk/pdf/GENE0110BRLG-e-e.pdf** [Accessed June 2013].

ENVIRONMENT AGENCY. 2010b. Don Catchment Flood Management Plan. URL: **http://publications.environment-agency.gov.uk/pdf/GENE0110BRLK-e-e.pdf** [Accessed June 2013].

ENVIRONMENT AGENCY. 2010c. Trent Catchment Flood Management Plan.

FARMING FUTURES. 2008. Fact Sheet 20: Climate Change: be part of the solution. Focus on soil management. Farming Futures URL: **www.hgca.com/publications/documents/cropresearch/FS20_Soil_management.pdf** [Accessed June 2013].

FOREST RESEARCH. 2010. Modelling the Impact of Climate Change on Tree Growth: Future species sustainability URL: **www.forestry.gov.uk/website/forestresearch.nsf/ByUnique/INFD-5ZXFSD** [Accessed June 2013].

GAMBOLATI, G., PUTTI, M.P. and GASPARETTO, S. 2003. Subsidence due to peat oxidation and impact on drainage infrastructure in a farmland catchment south of Venice Lagoons. *Environmental Geology*, 49, (6) 814-820, DOI: 10.1007/s00254-006-0176-6.

GILBERT G., BROWN, A.F., and WOTTON, S.R. 2010. Current dynamics and predicted vulnerability to sea-level rise of a threatened Bittern *Botaurus stellaris* population. *IBIS*, 152, 580-589.

GLICK, P., STEIN B.A., and EDELSON N.A. (eds). 2011. Scanning the Conservation Horizon: a guide to climate change vulnerability assessment. National Wildlife Federation, Washington, D.C.

GRAHAM, Tim B. 1997. Climate change and ephemeral pool ecosystems: potholes and vernal pools as potential indicator systems. In *Impacts of Climate Change and Land Use in the Southwestern United States*.

HANDMER, J.W. and DOVERS, S.R.1996. A Typology of Resilience: *Rethinking Institutions for Sustainable Development' Industrial and Environmental Crisis Quarterly*, 9 (4) 482-51.

HOPKINS, J *et al*. 2007. Conserving Biodiversity in a Changing Climate: Guidance on Building Capacity to Adapt. Department for Environment, Food and Rural Affairs, London.

HULME, M., JENKINS, G., LU, X., TURNPENNY, J.R., *et al*. 2002. Climate change scenarios for the United Kingdom: the UKCIP scientific report. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

HUMBERHEAD LEVELS PARTNERSHIP. 2008. Humberhead Levels Partnership Prospectus. (contact **inquiries.hlp@naturalengland.org.uk**).

INTER-AGENCY CLIMATE CHANGE FORUM. 2010. Biodiversity and climate change: a summary of impacts in the UK. (Eds. PROCTER, D.A., BAXTER, J.M., CRICK, H.P.Q., MORTIMER, D., MULHOLLAND, F ,WALMSLEY, C.A.). Joint Nature Conservation Committee, Peterborough.

IPCC. 2007. Climate change 2007 - Impacts, adaptation and vulnerability. Cambridge University Press, Cambridge.

ISAAC, S. 2009. The Climate Challenge for British Woodland. RTPI URL: **http://rtpi.org.uk/media/6065/Climate-change-and-woodland-article-SJ-Isaac.pdf** [Accessed June 2013].

JENKINS, G.J., MURPHY J.M., SEXTON, D.M.H., LOWE, J.A., JONES, P., KILSBY, C.G. 2009. UK climate projections: briefing report. Met Office Hadley Centre, Exeter, available at URL: **www.climatechangeandyourhome.org.uk/live/content_pdfs/883.pdf** [Accessed June 2013].

JONES, R.N., and MEARNS, L.O. 2005. Assessing Future Climate Risks: in LIM, B., E. SPANGER-SIEGFRIED, I. BURTON, E. MALONE and S. HUQ (Eds.), *Adaptation Policy Frameworks for Climate Change: Developing Strategies, Policies and Measures, Cambridge University Press, Cambridge and New York*, 119–144. URL: **www.preventionweb.net/files/7995_APF.pdf#page=124** [Accessed June 2013].

JNCC. undated. Vertebrate Species: mammals: Otter, *Lutra lutra* URL: **http://www.jncc.gov.uk/protectedsites/sacselection/species.asp?FeatureIntCode=S1355** [Accessed June 2013].

KECHAVARZI, C., DAWSON, Q., LEEDS-HARRISON P.B., SZATYLOWICZ, T., and GNATOWSKI, T. 2007. Water-table management in lowland UK peat soils and its potential impact on CO^2 emission. *Soil Use and Management,* 23, (4), 359-367.

KELLY, P.M. and ADGER, W.N. 2000. Theory and practice in assessing vulnerability to climate change and facilitating adaptation. *Climatic Change* 47, 325–352.

LAWTON, J.H., BROTHERTON, P.N.M., BROWN, V.K., ELPHICK, C., FITTER, A.H., FORSHAW, J., HADDOW, R.W., HILBORNE, S., LEAFE, R.N., MACE, G.M., SOUTHGATE, M.P., SUTHERLAND, W.J., TEW, T.E., VARLEY, J., & WYNNE, G.R. 2010. Making Space for Nature: a review of England's wildlife sites and ecological network. Report to Defra.

LLOYD, C. R. 2006. Annual carbon balance of a managed wetland meadow in the Somerset Levels, UK. *Agricultural and Forest Meteorology*,138,168-179.

LOCAL GOVERNMENT INFORMATION UNIT. 2010. Walk this Way: Recognising Value in Active Health Provision URL: **www.leedsmet.ac.uk/health/piph/documents/Walk%20This%20Way.pdf** [Accessed June 2013].

MACGREGOR, N.A., & COWAN, C.E. 2011. Government action to promote sustainable adaptation by the agriculture and land management sector in England: in J.D. FORD & L. BERRANG-FORD, eds. Climate change adaptation in developed nations: from theory to practice. Netherlands: Springer.

MAAS, J., VERHEIJ, R.A., de VRIES S., SPREEUWENBERG P., SCHELLEVIS F.G., GROENEWEGEN P.P. 2009. Morbidity is related to a green living environment. *Journal of Epidemiology and Community Health*. published online 15 Oct 2009; doi:10.1136/jech.2008.079038.

MAINSTONE, C. P., PARR, W., & DAY, M. 2000. Phosphorus and river ecology: tackling sewage inputs. Prepared on behalf of English Nature and the Environment Agency by Wrc. Peterborough, English Nature.

MANNING, A.D., FISCHER, J., FELTON, A., NEWELL, B., STEFFEN, W., LINDENMAYER, D.B. 2009. Landscape fluidity – A unifying perspective for understanding and adapting to global change. *Journal of Biogeography*, 36 (2), 193-199.

MCCORRY, M.J. and RENOU, F. 2003. Ecology and management of *Juncus effusus* (soft rush) on cutaway Peatlands. BOGFOR Research Programme. Forest Ecosystem Research Group. Report number 69.

MILLENNIUM ECOSYSTEM ASSESSMENT. 2005a. Ecosystems and Human Health: Water and Wetlands Synthesis. World Resources Institute. Washington DC, USA. 68pp.

MITCHELL, R.J., MORECROFT, M.D., ACREMAN, M., CRICK, H.Q.P., FROST, M., HARLEY, M., MACLEAN, I.M.D., MOUNTFORD, O., PIPER, J., PONTIER, H., REHFISCH, M.M., ROSS, L.C., SMITHERS, R.J., STOTT, A., WALMSLEY, C., WATTS, O., WILSON, E. 2007. England Biodiversity Strategy – Towards adaptation to climate change. Final Report to Defra for contract CR0327.

MORRIS, J., BAILEY A.P., LAWSON, C.S., LEEDS-HARRISON, P.B., ALSOP, D., VIVASH, R. 2008. The economic dimensions of integrating flood management and agri-environment through washland creation: A case from Somerset, England. *Journal of Environmental Management* 88 372–381.

MORRIS, J., POSTHUMUS, H., HESS, T.M., GOWING, D.J.G. and ROUQUETTE, J.R. 2009. Watery land: the management of lowland floodplains in England. In WINTER, M. and LOBLEY, M. (eds.).

MURPHY, J.M., SEXTON, D.M.H., JENKINS, G.J., BOORMAN, P.M., BOOTH, B.B.B., BROWN, CLARK, R.T., COLLINS, M., HARRIS, G.R., KENDON, E.J., BETTS, R.A., BROWN, S.J., HOWARD, T. P., HUMPHREY, K. A., MCCARTHY, M. P., MCDONALD, R. E., STEPHENS, A., WALLACE, C., WARREN, R., WILBY, R., WOOD, R. A. 2009. UK Climate Projections Science Report: Climate change projections. Met Office Hadley Centre, Exeter.

NATURAL ENGLAND. Undated, a. Draft Template for NCA Interim Objectives V4 (unpublished report).

NATURAL ENGLAND. 2010a. England's Peatlands: carbon storage and greenhouse gases. Natural England, Peterborough URL: **http://nepubprod.appspot.com/publication/30021** [Accessed June 2013].

NATURAL ENGLAND. Undated, c. Character Area 39: Humberhead Levels, Natural England, Peterborough URL: **www.naturalengland.org.uk/Images/jca39_tcm6-4983.pdf** [Accessed June 2013].

NATURAL ENGLAND. Undated, d. The Humberhead Levels Natural Area, Natural England, Cheltenham URL: **www.naturalareas.naturalengland.org.uk/Science/natural/NA_Details.asp?N=&R=3&NA_Id=22** [Accessed June 2013].

NATURAL ENGLAND. 2009a. Responding to the impacts of climate change on the natural environment: The Broads. NE114R, Natural England, Peterborough.

NATURAL ENGLAND. 2009b. Responding to the impacts of climate change on the natural environment: The Cumbria High Fells. NE115R, Natural England, Peterborough.

NATURAL ENGLAND. 2009c. Responding to the impacts of climate change on the natural environment: Dorset Downs and Cranborne Chase NE116R, Natural England, Peterborough.

NATURAL ENGLAND. 2009d. Responding to the impacts of climate change on the natural environment: Shropshire HillsNE117R, Natural England, Peterborough.

NATURAL ENGLAND. 2009e. No charge? Valuing the natural environment. Natural England.

NBN GATEWAY. Undated, a. Grid map of Records on the Gateway for European Otter (*Lutra lutra*) URL: **http://data.nbn.org.uk/gridMap/gridMap.jsp?allDs=1&srchSpKey=NBNSYS0000005133** [Accessed June 2013].

NBN GATEWAY. Undated, b. Grid Map of Records for Eurasian Marsh Harrier URL: **http://data.nbn.org.uk/gridMap/gridMap.jsp?allDs=1&srchSpKey=NHMSYS0000530293** [Accessed June 2013].

NBN GATEWAY. Undated, c. Grid map of Records on the Gateway for Common Darter (Sympetrum striolatum) URL: **http://data.nbn.org.uk/gridMap/gridMap.jsp?allDs=1&srchSpKey=NBNSYS0000005645** [Accessed June 2013].

NHS DATA MODEL AND DICTIONARY SERVICE. Undated. Lower Layer Super Output Area URL: **www.datadictionary.nhs.uk/data_dictionary/nhs_business_definitions/l/lower_layer_super_output_area_de.asp?shownav=1** [Accessed June 2013].

NOSS, R.F. 1983. A regional landscape approach to maintain diversity. *BioScience*, 33, 700-706.

O'CONNELL, P.E., BEVEN, K.J., CARNEY, J.N., CLEMENTS, R.O., EWEN, J., FOWLER, H., HARRIS, G.L., HOLLIS, J., O'DONNELL, G.M., PACKMAN, J.C., PARKIN, A., QUINN, P.F., ROSE, S.C., SHEPHERD, M. and TELLIER, S. 2004. Review of impacts of rural land management on flood generation. Impact Study Report. Defra R&D Technical Report FD2114/TR.

OPDAM P. and WASCHER, D. 2004. Climate change meets habitat fragmentation: linking landscape biogeographical scale levels in research and conservation. *Biological Conservation*, 117, 285-297.

PAKEMAN, R.J. and MARRS, R.H. 1996. Modelling the effects of climate change on the growth of bracken (*Pteridium aquilinum*) in Britain. *Journal of Applied Ecology*, 33 (561-575).

PARLIAMENTARY OFFICE OF SCIENCE AND TECHNOLOGY. 2007. Postnote Number 281: Ecosystem Services URL: **www.parliament.uk/documents/post/postpn281.pdf** [Accessed June 2013].

PARRY, M.L. and CARTER,T. 1998. Climate Impact and Adaptation Assessment. Earthscan, London.

POND CONSERVATION. Undated. Temporary Ponds URL: **www.pondconservation.org.uk/advice/definitionofapond/temporaryponds** [Accessed June 2013].

READ, D.J., FREER-SMITH, P.H., MORISON, J.I.L., HANLEY, N., WEST, C.C. and SNOWDON, P. (eds.). 2009. Combating climate change – a role for UK forests. An assessment of the potential of the UK's trees and woodlands to mitigate and adapt to climate change. The Stationery Office, Edinburgh.

ROSENZWEIG, C., KAROLY, D., VICARELLI, M., NEOFOTIS, P., WU, Q., CASASSA, G., MENZEL, A., ROOT, T.L., ESTRELLA, N., SEGUIN, B., TRYJANOWSKI, P., LIU, C., RAWLINS, S. & IMESON, A. 2008. Attributing physical and biological impacts to anthropogenic climate change. *Nature*, 453, 353–357.

SEAGO, M.J., (undated). Marsh Harrier, Birds of Britain, [online] URL: **www.birdsofbritain.co.uk/bird-guide/marsh-harrier.asp** [Accessed June 2013].

SELMAN, DODD AND BAYES. 1999. A Biodiversity Audit of Yorkshire and the Humber. Yorkshire and Humber Biodiversity Forum.

SCOTTISH EXECUTIVE. 2006. Peat Landslide Hazard and Risk Assessments: Best Practice Guide for Proposed Electricity Generation Developments. URL: **www.scotland.gov.uk/Publications/2006/12/21162303/2** [Accessed June 2013].

SOWAP. 2007. Impact of Conservation Tillage on Soil Erosion and runoff URL: **www.cranfield.ac.uk/sas/nsri/research/projects/sowap.html** [Accessed June 2013].

SMITHERS, R.J., COWAN, C., HARLEY, M., HOPKINS, J.J., PONTIER, H. and WATTS, O. 2008. England Biodiversity Strategy Climate Change Adaptation Principles: conserving biodiversity in a changing climate, Defra, London.

STEFFEN, J., BURBIDGE, A., HUGHES, L., KITCHING, R., LINDENMAYER, D., MUSGRAVE, W., STAFFORD SMITH, M., WERNER P. 2009. Australia's Biodiversity and Climate Change: A Strategic Assessment of the Vulnerability of Australia's Biodiversity to Climate Change. Technical synthesis of a report to the Natural Resource Management Ministerial Council commissioned by the Australian Government. Department of Climate Change, Canberra.

SWIFT, R. S. 2001. Sequestration of Carbon by soil. *Soil Science* 166 (11): 858–71.

THE INDEPENDENT. 13 July 2010. '60 miles of canal closed in drought' URL: **www.independent.co.uk/news/uk/home-news/60-miles-of-canal-closed-in-drought-2025712.html** [Accessed June 2013].

THE PITT REVIEW. Learning lessons from the 2007 floods: an independent review by Sir Michael Pitt, June 2008.

THORNE-MOORENDS TOWN COUNCIL. (undated). Humberhead Peatlands – Thorne Moors – Hatfield Moors URL: **www.thorne-moorends.gov.uk/other/thorne_moors.html** [Accessed June 2013].

TRANSPENNINE TRAIL. 2011. Current diversions and Closures – central. URL: **www.transpenninetrail.org.uk/template.asp?ID=652&parentID=495** [Accessed June 2013].

TRENT VALLEY GEOARCHAEOLOGY. Undated. Trent Valley Geoarchaeology URL: **www.tvg.bham.ac.uk/** [Accessed June 2013].

UKBAP. Undated. UK Biodiversity Action Plan: Priority Habitat Descriptions URL: **http://jncc.defra.gov.uk/PDF/UKBAP_PriorityHabitatDesc-Rev2011.pdf** [Accessed June 2013].

UKBAP. 2010a. Habitat Action Plan: Fen, Marsh and Swamp.

UKBAP. 2010b. Habitat Action Plan: Purple Moor Grass and Rush Pasture.

UK CLIMATE IMPACTS PROGRAMME (n.d). Identifying adaptation options. URL: **www.ukcip.org.uk/wordpress/wp-content/PDFs/ID_Adapt_options.pdf** [Accessed June 2013].

UKCIP. 2010. Key Findings for Yorkshire and Humber, 2080s: Medium Emissions Scenario URL: **http://ukclimateprojections.defra.gov.uk/22356** [Accessed June 2013].

WALTERS, C. 1997. Challenges in Adaption Management of Riparian and Coastal Ecosystems. *Conservation Ecology* 1 (2):1

WIGAN LEISURE AND CULTURE TRUST. Undated. What is Land For? The Food, Fuel and Climate Change Debate. Earthscan. pp.320. ISBN 9781844077205. Bittern URL: **www.wlct.org/WLCT/wigan/assets/biodiversity/bittern.pdf** [Accessed August 2013].

WILBY. R.L., ORR, H., WATTS, G., BATTARBEE, R.W., BERRY, P.M., CHADD, R., DUGDALE, S.J., DUNBAR, M.J., ELLIOTT, J.A., EXTENCE, C., HANNAH, D.M., HOLMES, N., JOHNSON, A.C., KNIGHTS, B., MILNER, N.J., Ormerod, S.J., SOLOMON, D., TIMLETT, R., WHITEHEAD P.J., and WOOD P.J. 2010. Evidence needed to manage freshwater ecosystems in a changing climate: Turning adaptation principles into practice. *Science of the Total Environment*, 408, (19), 4150-4164.

WILLIAMS, S.E., SHOO, L.P., ISAAC, J.L., HOFFMAN, A.A. and LANGHAM, G. 2008. Towards an Integrated Framework for Assessing the Vulnerability of Species to Climate Change. *PLoS Biology* 6 (12).

WILLOWS, R.I. and CONNELL, R.K. (eds). 2003. Climate adaptation: Risk, uncertainty and decision making: UKCIP Technical Report, UKCIP, Oxford.

YORKSHIRE AND HUMBER ASSEMBLY. 2009. Yorkshire and Humber Climate Change Adaptation Study. URL: **www.homesandcommunities.co.uk/download-doc/3925/8401** [Accessed June 2013].

YORKSHIRE POST. 29 August 2008. Cranes breed again at Yorkshire Reserve. URL: **www.yorkshirepost.co.uk/bird-watching/cranes-breed-again-at-Yorkshire.4442472.jp** [Accessed June 2013].

Appendix 1 Vulnerability tables of key landscape assets

Table A Results of vulnerability assessment for habitats and species

Habitat	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Running water	Wetter winters Intense rainfall Hotter summers Drier summers Sea level rise	Sensitive to drought leading to reduced flow, flooding leading to submergence of bankside habitats, high water temperature, nutrient enrichment and eutrophication (in many sites sources of nutrients may come from upstream sources outside the NCA), invasive species and high tides. Large reaches of the lowland rivers (Aire, Don, Idle) have sparse riparian/bank vegetation cover increasing their vulnerability.	Environmental: Bankside and riverine vegetation can increase adaptive capacity. Management: Adaptive capacity reduced due to increase in water demand in extreme dry periods. External pressures such as pollutant / nutrient inputs can reduce adaptive capacity. Modification pressures (for example, weirs, flood defences) can also reduce adaptive capacity.	**More vulnerable** **11 (8)**	O'Connell *et al.*, 2004 Mainstone 2000 Conlan *et al.*, 2007. Wilby *et al.*, 2010
Lowland raised mire	Wetter winters Drier summers Sea level rise	Sensitive to flooding, soil water deficit, increased risk of fire, and coastal flooding. This may lead to increased risk of 'bog burst', erosion of peat, reduced success when restoring habitat, drying and oxidation of peat followed by release of nutrients, increased risk of inundation from the sea or from high rainfall. Indirect effects of climate change may be significant, including the effect of increased water drainage on surrounding land resulting in hydrological effects.	Environmental: Bogs are ombrotrophic, or rainfall fed, making adaptation extremely difficult if summer rainfall is deficient. Management: Continue management to improve condition and legacy of historical drainage restrict adaptive capacity.	**More vulnerable** **10 (11)**	

Table continued…

Habitat	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Coastal and floodplain grazing marsh and floodplain hay meadow	Hotter summers Drier summers Wetter winters Intense rainfall Sea level rise	Sensitive to higher water temperature, higher evapotranspiration, soil and water deficit, drought, flooding, higher intensity rainfall and saline intrusion. This may lead to changes in species composition, loss of breeding and feeding habitat for wetland birds, increased silt loading during inundation episodes, loss of botanical diversity if floods occur at the wrong time of year, loss of freshwater marsh species.	Environmental: Adaptive capacity reduced through coastal squeeze Management: Adaptive capacity may be reduced as other forms of agriculture become viable (for example biomass). Design and location of flood defences can also affect adaptive capacity.	**More vulnerable** **10 (6)**	
Lowland heathland	Hotter summers Drier summers Wetter winters	Sensitive to longer growing season, drought, and increased runoff leading to changes in community composition, loss of bare ground areas due to growth of plants, more heather beetle attacks on heather, loss of certain species, and increased risk of wild fires.	Management: The adaptive capacity of this habitat will be enhanced if grazing management is adjusted to negate climate change effects.	**Moderately vulnerable** **7 (6)**	
Carr woodland	Hotter summers Drier summers Sea level rise	Sensitive to drought and tidal flooding leading to changes in ground flora communities, drying out of rainfall dependent sites in summer. In some cases wet woodland may benefit from increased fluvial inundation.	Environmental: Rainfall dependent sites likely to have low adaptive capacity. Very scarce resource in NCA. Management: Adaptive capacity dependant on ability to maintain water levels and increase the size of sites.	**Moderately vulnerable** **1 (7)**	(Isaac, undated) Although this scored in the first quartile, its scarcity in the NCA, the value accorded to it by consultees, and its status in other NCAs has meant that in this summary table the RAG status has been upgraded to amber.

Table continued…

Habitat	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Lowland deciduous woodland/ Ancient woodland fragments	Intense rainfall Hotter summers Drier summers Warmer winters	Sensitive to wind blow and drought leading to loss of trees, fire risk and impacts from pest species.	Environmental: The fragmented nature of ancient woodland in the NCA impairs adaptive capacity. Management: Buffering of sites and increasing permeability of the landscape for species associated with ancient woodland and trees can increase adaptive capacity.	**Moderately vulnerable** **4 (3)**	
Hedgerows	Hotter summers Drier summers Warmer winters Drier winters Intense rainfall	Sensitive to longer growing season, fewer frost events, reduced soil moisture, drought and high winds leading to increased shading of herbaceous flora, less winter chill conditions for regeneration of berry bearing hedgerow species, reduction in wet ditch/hedgerow edge habitat, increased die back or wind blow of hedgerow trees in vulnerable locations.	Management: Often neglected though agri-environment schemes have encouraged hedgerow planting, increasing adaptive capacity. Varied and appropriate hedgerow management will further increase adaptive capacity.	**Moderately vulnerable** **3 (4)**	
Ditches	Wetter winters Hotter summers Drier summers Intense rainfall	Sensitive to drought leading to reduced water levels, nutrient enrichment, siltation and eutrophication, invasive species, rapid vegetation succession.	Environmental: Ditches prone to siltation and loss of connection with other freshwater habitats. Management: External pressures, for example, nutrient and sediment inputs can reduce adaptive capacity.	**Moderately vulnerable** **6 (8)**	
Reedbeds	Intense rainfall Sea level rise Drier summers	Sensitive to high intensity rainfall, flooding, soil water deficit, drying out of pools (containing fish and aquatic mammals and invertebrates), coastal flooding. This could lead to loss of associated species due to inundation and poor water quality; fish kills associated with drying out events, and increased salinity.	Management: Adaptive capacity may be compromised by increased water extraction on adjacent farmland and the erection of barriers, such as flood defences, preventing egress from habitat.	**Moderately vulnerable** **7 (6)**	

Table continued…

Habitat	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Fen habitats	Hotter summers Drier summers Wetter winters Intense rainfall Sea level rise	Sensitive to higher water temperatures, higher evapotranspiration, soil moisture deficit, drought, flooding, high intensity rainfall and saline intrusion and flooding. This may lead to shift in community composition, drying out of fens in summer, oxidation of peat and subsequent release of nutrients, ingress of pollutants and nutrients in runoff during times of higher rainfall, and loss of sites to sea level rise.	Environmental: Fens encompass a wide range of habitat types, many of which will respond to climate change in different ways. Management: In some places the adaptive capacity of fen habitats may be constrained by water abstraction and / or nutrient enrichment from runoff from surrounding land.	**Moderately vulnerable** **7 (8)**	
Urban greenspace	Hotter summers Drier summers Intense rainfall	Sensitive to drought, flooding and increased growing season leading to an increased demand for management. Indirectly warm weather may encourage more people to visit urban green spaces, increasing the exposure to recreational pressure and fire risk.	Management: Where well managed, the potential for practicing adaptive management is good. Simple measures such increasing organic matter in soils and mulching will increase resilience.	**Less vulnerable** **2 (0)**	
Purple moorgrass and rush pasture	Hotter summers Drier summers Wetter winters.	Sensitive to drought, changes in height of water table and a longer growing season leading to loss of some mire species, scrub invasion / woodland succession or shift in habitat type to fen or swamp in wet conditions.	Environmental: Many sites have been lost to agricultural improvement – now a fragmented habitat. Management: Adjustment to water level and grazing regimes and reduction of water abstraction pressures will help increase capacity.	**Less vulnerable** **1 (1)**	
Arable field margins	Hotter summers Intense rainfall	Sensitive to drought and flooding leading to loss of food and refuge resources provided by habitat and increased weed growth.	Management: Potential to be managed through agri-environment schemes.	**Less vulnerable** **1 (0)**	

Table continued…

Habitat	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Flooded gravel pits and flashes	Hotter summers Drier summers Warmer winters Intense rainfall	Sensitive to higher water temperature, longer growing season, drought and reduced water levels, and higher intensity rainfall. These factors may lead to eutrophication, toxic algal blooms, invasive species, exposure of littoral communities and loss of connection with other freshwater habitats.	Environmental: Isolated wetlands have lower adaptive capacity. Management: Other pressures can reduce adaptive capacity, for example, nutrient and sediment loads, non-native plant and animal species, Increase water retention capacity within catchment.	**Less vulnerable** **0 (1)**	The Trent Catchment Flood Management Plan considers the effects of flooding on some of the gravel pits, suggesting that the effect on Sutton and Lound Gravel Pits SSSI will be negative.

Table B Vulnerability of iconic species to the impacts of climate change

Species	Potential exposure	Sensitivity	Adaptive capacity	Relative vulnerability rating and score (value scores)	Notes and references
Bittern	Drier summers Intense rainfall Sea level rise	Bitterns' habitat of reedbeds is sensitive to drying out and nutrient enrichment / salinisation. This could reduce availability of bittern food and habitat.	Management: Adaptive capacity may be reduced by water extraction due to increased demand in dry periods.	**No score**	Populations of bittern are at a very low level, and their habitat is particularly sensitive to climate change. To reflect this, and evidence cited in studies such as that of Gilbert *et al.,* (2010), a red vulnerability rating has been given.
Otter	Hotter summers Drier summers Intense rainfall	Otter habitat sensitive to drought, leading to declining water quality. This may lead to rivers containing less prey for otters.	Management: Adaptive capacity further reduced by increases in water demand during dry periods.	**No score**	
Common Crane	Drier summers Intense rainfall Sea level rise	Increasingly dry summer weather may affect common crane prey availability. Habitat loss due to wildfire or sea level rise may also occur.	Environmental: Common crane will breed in a variety of shallow wetlands, so is not restricted to just one wetland type, thus increasing resilience. Management: Increasing managed re-alignment or wetland schemes could increase adaptive capacity.	**No score**	Given crane's adaptive capacity is high, it is thought that vulnerability to climate change is likely to be low, so long as a range of wetland habitats continues to exist in the NCA.
Marsh Harrier	Drier summers	Drying out of ponds or siltation will reduce habitat availability for this species.	Environmental: Marsh harrier may be able to switch habitat requirements to arable land in some cases.	**No score**	
Common darter	Intense rainfall Drier summers	Drying out of ponds or siltation will reduce habitat availability for the species.	Management: Increasing popularity of garden ponds and opportunities for on farm water storage could increase adaptive capacity.	**No score**	

Table C Results of vulnerability assessment for soils, geological and geomorphological assets

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value scores)	Notes and references
Peatland	Hotter summers Drier summers Wetter winters Sea level rise Intense rainfall	Sensitive to drying out of peat, increased risk of fire, flooding, coastal flooding and increased frequency of storms leading to oxidation and erosion of peat, peat lost to fire, erosion of peat, and increased risk of inundation. Indirect effects such as nutrient enrichment through flooding may cause additional plant growth to damage peat sequences and cause drying out.	Environmental: Adaptive capacity affected by historical impacts of drainage. Management: Adaptive capacity will depend on the ability to maintain water levels.	**More vulnerable** **14 (14)**	
Gravel pits and quarries with exposed sandstones and gravels	Hotter summers Drier summers Intense rainfall Wetter winters	Sensitive to drought, longer growing season, flooding, increased weathering and erosion rate, and flooding. This may lead to increased vegetation growth, or landslides obscuring exposures, new features being exposed beyond SSSI site boundaries, reduced access to exposures and flooding of pits obscuring or damaging interest features. Indirect effects may include that sites may become valuable for reasons other than geodiversity, such as for nature conservation or flood storage.	Environmental: In situ nature of assets will reduce adaptive capacity. Management: Site interest features may be obscured as priorities for use change, (for instance sites may be become valuable for nature conservation, or may be 'filled in' for safety reasons). This may constrain efforts to manage for resilience.	**Moderately vulnerable** **5 (6)**	
Raised bog peat soils	Hotter summers Drier summers	Sensitive to higher temperatures and drought. This may lead to degradation of the asset and loss of a major carbon sequestration resource.	Environmental: Adaptive capacity affected by historical impacts of drainage. Management: Good land management can minimise soil deterioration and increase adaptive capacity.	**More vulnerable** **6 (8)**	

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value scores)	Notes and references
Loamy and clayey floodplain soils with naturally high groundwater	Wetter winters Intense rainfall	Sensitive to water logging, flooding and erosion. This may lead to fewer work days for arable cultivation, increased risk of soil compaction, soil loss and sediment deposition. Changes in cropping due to climate change may also affect the erosion rates of this soil type.	Management: Good land management can minimise soil deterioration, improve soil structure, and increase adaptive capacity.	**Moderately vulnerable** **10 (2)**	
Naturally wet very acid sandy and loamy soils	Hotter summers Drier summers Intense rainfall	Sensitive to drought, increased soil moisture deficit, erosion and high winds. This may lead to bare soils eroding or well drained soils becoming more drought prone. Changes in cropping due to climate change may also affect the erosion rates of this soil type.	Management: Good land management can minimise soil deterioration, improve soil structure, and increase adaptive capacity.	**Less vulnerable** **0 (5)**	Although this soil is considered valuable, voters did not award it any vulnerability score in workshops. It has been awarded green status to reflect the fact that it was not ranked as vulnerable.
Slowly permeable seasonally wet slightly acid but base-rich loamy and clayey soils	Wetter winters Intense rainfall	Sensitive to water-logging and increased water run-off. This may lead to fewer work days for arable cultivation, increased risk of soil compaction or greater difficulty when managing soils.	Management: Good land management can minimise soil deterioration and increase adaptive capacity. Drainage of soils must be functional.	**Less vulnerable** **4 (0)**	
Freely draining slightly acid sandy soils	Drier summers Wetter winters Intense rainfall	Sensitive to drought, increased soil-moisture deficit and erosion. Sandy soils may become increasingly drought prone and vulnerable to water and wind erosion. Changes in cropping due to climate change may also affect the erosion rates of this soil type.	Management: Good land management can minimise soil deterioration and increase adaptive capacity. Existing pressures, for example, sediment loading can reduce adaptive capacity.	**Less vulnerable** **4 (0)**	

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value scores)	Notes and references
Loamy and clayey soils of coastal flats with naturally high groundwater	Sea level rise	Sensitive to coastal flooding. This may result in salinisation or loss of asset.	Environmental: Adaptive capacity reduced through coastal squeeze	**Less vulnerable** **0 (2)**	
Freely draining slightly acid loamy soils (for example, South Doncaster area)	Drier summers Wetter winters Intense rainfall	Sensitive to drought, increased soil moisture deficit, and erosion.	Environmental: Coarser textured soils may become increasingly drought prone while less clayey or shallow variants of this soil type may become more prone to erosion. Management: Good land management can minimise soil deterioration and increase adaptive capacity.	**No score**	
Loamy soils with naturally high groundwater	Wetter winters Intense rainfall	Sensitive to water-logging and increased runoff. This may lead to fewer work days for arable cultivation and increased risk of soil compaction.	Management: Good land management can minimise soil deterioration and increase adaptive capacity. Drainage of soil must be functional.	**No score**	
Loamy and sandy soils with naturally high groundwater and a peaty surface	Drier summers Hotter summers	Sensitive to drought, higher temperatures, possible reduction in groundwater level, high winds and erosion. Loss of soil carbon, greater difficulty draining land due to lower land levels (arising from peat loss) and wind erosion may occur. Changes in cropping due to climate change may also affect the erosion rates of this soil type.	Management: Good land management can minimise soil deterioration and increase adaptive capacity. Drainage of soil must be functional.	**No score**	

Table D Results of the vulnerability assessment for historic environment assets

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Palaeo-environmental records and remains in alluvial valleys	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to repeated wetting and drying episodes leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. Increased growth of deep rooted plants may also affect assets. More flooded sites may make them less accessible. Erosion and structural damage may occur.	Environmental: Low adaptive capacity as assets remain in situ. Management: Adaptation responses can reduce adaptive capacity, for example, habitat creation on peat deposits and flood defence works.	**More vulnerable** **No score (see notes)**	(Trent Valley Geoarchaeology undated)[12] Although no score was awarded to this category, there was a strong feeling amongst consultees on this report that the potential sensitivity of this asset to a range of impacts, as well its low adaptive capacity makes it potentially one of the most vulnerable historic assets in the NCA. It has therefore been rated as more vulnerable.
Pre-historic settlements on sand and gravel outcrops and their associated field systems	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to warmer weather leading to increased growth of deep rooted plants. More flooded sites may make them less accessible. Erosion and structural damage may occur. Repeated wetting and drying episodes may potentially be an issue.	Environmental: Low adaptive capacity as assets remain in situ. Management: Over grazing and deep ploughing can reduce adaptive capacity.	**More vulnerable** **4 (0)**	

Table continued…

[12] The Trent Valley Geoarchaeology website features a range of studies on the archaeological heritage of alluviated sites (see **www.tvg.bham.ac.uk/**)

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Commons (for example, Skipwith, Allerton, Thorne and Hatfield and their associated turbaries)	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. This may lead to loss of historic assets. More flooded sites may make them less accessible.	Environmental: Cannot be replaced once lost. Management: Can be managed to increase adaptive capacity. Habitat management uninformed by historic interest may reduce adaptive capacity.	**More vulnerable** **6 (8)**	
Roman farmsteads, roads	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. Increased growth of deep rooted plants may also affect assets. More flooded sites may make them less accessible. Erosion and structural damage may occur.	Environmental: Cannot be replaced once lost. Management: Can be managed to increase adaptive capacity.	**Moderately vulnerable** **1 (4)**	
Mediaeval landscapes (for example, Isle of Axholme)	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. Drying out and cracking will damage and expose sites and assets. Increased growth of deep rooted plants may also affect assets. More flooded sites may make them less accessible.		**Moderately vulnerable** **1 (3)**	

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Ecclesiastical sites (for example, Archbishops Palace at Cawood, Augustinian Priory at Drax, Ellerton Priory, Axholme Carthusian Priory)	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought. Subsidence may occur. More flooded sites may make them less accessible. Erosion and structural damage may occur.	Environmental: Cannot be replaced once lost. Management: Can be managed to increase adaptive capacity.	**Moderately vulnerable** **1 (0)**	English Heritage, 2004a English Heritage, 2004b English Heritage, undated
Ancient trees with historic / cultural value	Intense rainfall	Ancient trees are sensitive to flooding, including coastal flooding, erosion and high winds. This may lead to erosion to sites or structural damage to trees as a result of high winds[13].	Environmental: Low adaptive capacity as cannot be replaced once lost.	**Moderately vulnerable** **1 (2)**	
Marine-based HE resources in the Humber Estuary (for example, submerged landscapes, inter-tidal features, wrecks and other debris)	Wetter winters Warmer winters Sea level rise	Sensitive to flooding, water-logging of soils, longer growing season. This may lead to erosion and structural damage, more flooded sites making them less accessible and causing damage and erosion, more frequent wetting and drying episodes, sites disappearing below water, detail of historic drains being obscured and the historic pattern of previous coastal and inter-tidal features becoming unreadable.	Environmental: Low adaptive capacity as cannot be replaced once lost. Management: Flood defence works implemented to adapt to a changing climate may reduce adaptive capacity.	**Less vulnerable** **0 (1)**	

Table continued…

[13] Ancient trees are often part of designed landscapes, so loss of ancient trees may damage the integrity of these historic landscapes

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Iron-age and Romano-British industrial sites (for example, Foulness valley)	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. Increased growth of deep rooted plants may also affect assets. More flooded sites may make them less accessible. Erosion and structural damage may occur.	Environmental: Low adaptive capacity as assets remain in situ.	**Less vulnerable** **No score**	No score was awarded to this asset at the stakeholder workshops. It has therefore not been given a RAG status.
Bog oaks	Drier summers Hotter summers Warmer winters Wetter winters	Sensitive to drought leading to soil erosion, increased soil moisture deficit and changes in soil chemistry. There may be an enhanced fire risk to this asset. More flooded sites may make them less accessible.	Environmental: Cannot be replaced once lost. Management: Where it is not possible to conserve in situ, assets should be fully recorded	**Less vulnerable** **No score**	No score was awarded to this asset at the stakeholder workshops. It has therefore not been given a RAG status.
Marine-based HE resources in the Humber Estuary (for example, submerged landscapes, inter-tidal features, wrecks and other debris)	Wetter winters Warmer winters Sea level rise	Sensitive to flooding, water-logging of soils, longer growing season. This may lead to erosion and structural damage, more flooded sites making them less accessible and causing damage and erosion, more frequent wetting and drying episodes, sites disappearing below water, detail of historic drains being obscured and the historic pattern of previous coastal and inter-tidal features becoming unreadable.	Environmental: Low adaptive capacity as cannot be replaced once lost. Management: Flood defence works implemented to adapt to a changing climate may reduce adaptive capacity.	**Less vulnerable** **0 (1)**	

Table E Results of the vulnerability assessment for access and recreation

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Waterways	Hotter summers Drier summers Wetter winters Sea level rise Intense rainfall	Sensitive to drought, higher water levels flooding and higher tidal reach. This may lead to lower water levels, loss of riparian access, algal blooms impacting on amenity value, bank erosion, and more challenging conditions for water based activity. In addition, warmer weather may lead to increased usage of waterways for recreation, which may exacerbate certain problems such as bank erosion.	Environmental: Certain events such as long periods of drought may be difficult to address. Management: Many waterways are already heavily managed; therefore managed responses to climate change may often be possible.	**More vulnerable** **6 (10)**	
Rights of way network	Hotter summers Drier summers Warmer winters Wetter winters Intense rainfall Sea level rise	Sensitive to higher demand from walkers/riders, longer growing season, water-logging of soil, erosion and coastal flooding. This may lead to greater path surface erosion, path edge erosion, overgrown path edges, muddy and slippy path surfaces, bridges washed away, other infrastructure damage and loss of routes below sea level. As climate becomes generally warmer, more people will use the rights of way network more often. Where other problems do not hinder access it is likely climate change will have a positive effect on levels of use.	Environmental: Existing condition of some paths and coastal squeeze may reduce adaptive capacity at the coast. Management: The financial ramifications of a greater need for footpath maintenance may also reduce adaptive capacity.	**More vulnerable** **9 (5)**	

Table continued...

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Open access land	Hotter summers Drier summers Warmer winters Wetter winters Intense rain Sea level rise	Sensitive to drought, wildfire, erosion, water logging of soils. This may lead to drying out of peatlands leading to greater surface erosion, wetter conditions deterring visitors (conversely warmer conditions may attract more), damage to vegetation and surface, and increased inundation of low-lying areas.	Environmental: Extent of open access land means that some impacts on recreational value may be more readily absorbed by open access sites. However, fire events in particular have the capacity to severely diminish the value of open access land as a recreational resource.	**Moderately vulnerable** **2 (3)**	
Local Authority LNRs and other sites	Hotter summers Drier summers Intense rainfall	Sensitive to drier weather, which could increase visitor demand causing problems such as erosion and disturbance of wildlife. However storm damage may hinder access or detract from user experience. As they are designated for a wide range of site specific features, the features of LNRs may suffer from a wide range of climate related impacts. This may diminish their educational value, particularly if interest features are lost or damaged.	Management: A number of LNRs place visitor management at the centre of their management plans. They are therefore well placed to increase adaptive capacity.	**Moderately vulnerable** **3 (2)**	Although at the lower end of the higher (above third tercile) values in terms of score, the distribution of scores contains more lower values. This, coupled with the broad range of LNR types has resulted in a RAG status of amber rather than red.
Woodlands with formal or informal access	Drier summers	Sensitive to drier weather which could increase visitor demand. This could cause disturbance of wildlife, increased erosion and increased fire risk.	Management: Adaptive capacity may be constrained by financial resources.	**Moderately vulnerable** **2 (1)**	
Urban green space	Drier summers Hotter summers Wetter winters	Sensitive to increased visitor pressure, drying of planted areas and flooding.	Management: Many urban green spaces are closely managed and have high adaptive capacity. Some urban green spaces remain unmanaged, and their adaptive capacity is reduced.	**Moderately vulnerable** **2 (1)**	

Table continued…

Asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Routes along estuary flood bank	Hotter summers Drier summers	Sensitive to increased recreation pressure causing erosion and greater need for maintenance of flood bank.	Management: Adaptive capacity could be constrained by in situ nature of asset and the primary need to ensure flood defence sustainability.	**Moderately vulnerable** **No score**	Although not scored, consultees felt that the asset was somewhat vulnerable to climate change. It has therefore been given amber status in this report.
Permissive routes	Hotter summers Drier summers Wetter winters	Sensitive to increased visitor pressure disturbing livestock and increasing erosion. Flooding may also lead to erosion.	Management: Good adaptive capacity as management is already in place.	**Less vulnerable** **1 (0)**	

Table F Results of the vulnerability assessment for other aspects of landscape form

Landscape characteristic or asset	Potential exposure	Sensitivity	Adaptive capacity	Vulnerability rating and score (value score)	Notes and references
Productive land in large scale, geometric field patterns	Drier summers Hotter summers Wetter winters Intense rainfall	Sensitive to increased soil moisture deficit, water logging of soils and a longer growing season. This may lead to changing cropping patterns, and the taking of two crops per year.	Management: Highly managed. Changes will be largely market led.	**More vulnerable** **7 (7)**	
Historic landscapes and settlement patterns	Drier summers	Sensitive to drought and wind erosion of peat soils. This may lead to drying out and oxidation of peat soils and the loss of historic field patterns as new crops are grown.	Environmental: Peat soils likely to have lowest adaptive capacity. Management: Changes to agricultural practice will largely be market led, though there may be potential to incentivise retention of historic landscape assets through targeting of agricultural payment schemes.	**More vulnerable** **7 (1)**	
Flat, open expansive views	Drier summers Wetter winters	Sensitive to drought and flooding.	Management: The policy response to climate change may lead to more renewable energy production which may alter views.	**Moderately vulnerable** **2 (0)**	
Flood plains adjacent to the Humber Estuary	Wetter winters Intense rainfall Sea level rise	Sensitive to flooding and coastal flooding. This in turn may lead to the building of higher flood defences and the creation of more flood storage areas.	Management: Adaptive capacity may be constrained by flood defences. Opportunities to create new habitats may increase adaptive capacity.	**Moderately vulnerable** **3 (2)**	
Local variation due to glacial drift deposits	Hotter summers Drier summers Wetter winters Warmer winters Sea level rise	Sensitive to drought, soil water deficit, a longer growing season and the water-logging of soils. This may lead to a stressed appearance to trees on sandy soils and longer periods in which land is being cropped.	Management: Good land management can increase water retention in soils. Positive changes may occur (for instance more land in pasture).	**Less vulnerable** **0 (1)**	
Plantations (on sandy soils)	Drier summers	Sensitive to increased soil water deficit. This could lead to stressed trees and loss of trees in drought conditions.	Management: Most plantations are already managed so high management capacity.	**Less vulnerable** **1 (0)**	

Appendix 2 Implications of the vulnerability assessment for landscape character, ecosystem services and biodiversity

Landscape character

A low-lying area of the former pro-glacial Lake Humber often falling below the mean water level with drift deposits including glacial tills, clays, peat, gravel and wind-blown sand which give local variation to landscape character. The underlying geomorphology that gives the NCA its low lying character is unlikely to be vulnerable to climate change. The shape of the landscape is thus unlikely to change although the appearance may alter as land use responds to the impacts of climate change.

Waterlogged archaeological remains and palaeo-environmental deposits of international importance in the Trent floodplains. Historic environment assets which contribute to the character of the NCA may be highly vulnerable to climate change as once they are lost they cannot be replaced. It is therefore possible that this aspect of the landscape could be diminished unless it is managed appropriately.

Essentially flat, very open character with distant views and big skies, and occasional rising ground formed by ridges of sand and outcrops of Mercia Mudstone. Increasing demand to place engineered structures in the landscape to counter climate change impacts or supply renewable energy may together result in a more cluttered landscape. Although views are likely to remain extensive due to the topography of the NCA, in some places sight lines may be diminished due to features such as raised flood embankments. However, without flood defences much of this area would be vulnerable to fluvial flooding and sea level rise.

Extensive floodplains, washlands, saltmarsh and traditionally grazed alluvial flood meadows (Ings) associated with navigable rivers. The vulnerability assessment has highlighted that these habitats may be vulnerable to climate change. It is therefore possible that the matrix of habitats which contribute to the character of the NCA will change over time, giving the area a different appearance. The presence of estuarine / coastal habitats in the landscape could be reduced through coastal squeeze and areas currently covered by freshwater habitats could shift to more saline habitats. However, an increase in flooding could result in greater areas of floodplain habitats as they become more significant for flood defence, making this aspect of landscape character even more prominent.

Peat bogs and raised mires. These distinctive features of the Character Area are highly valued for their biodiversity and historic qualities and are highly vulnerable to climate change. A range of pressures resulting from climate change may act together to reverse the recent improvements in habitat quality made at iconic sites such as Thorne and Hatfield Moors. Vulnerabilities arising from periods of flooding and drying, such as nutrient enrichment and ‘bog burst’ could give these habitats a more degraded feel, detracting from the sense of wilderness that is currently experienced by visitors. In addition, shock events, such as fires, should they occur, can completely alter the character of these large scale features in a matter of days.

Rich and fertile farmland. Given the range of soils in the Character Area, some areas may be more vulnerable to climate change than others. Several soil types are seen as vulnerable to water logging, erosion and compaction. Crops grown are likely to change in reaction to a changing climate, and good land management can lessen the impacts of climate change, therefore the NCA is likely to continue to look and feel like a productive farming area. The potential for taking two crops per year, instead of one will also change the texture and hue of winter landscapes.

Small amounts of carr woodland and rare alder woodland. These small patches of woodland will be vulnerable to drying out, which may ultimately result in shifts in ground flora and tree species composition. However, shifts in rainfall patterns may mean that new carr woodlands start to grow elsewhere. Wet woodland is often a transitional state in the ecological succession between wetlands and the development of dryer woodland types. It may be that climate change accelerates such succession, though it is difficult to predict whether new wet woodland will be allowed to develop elsewhere if conditions allow. Therefore, the overall effects on landscape character are uncertain.

Flooded gravel pits and subsidence flashes. The NCA’s key large water bodies may suffer from more nutrient loading, giving them a less pleasant appearance, and thus negatively impacting on the landscape character of the area at a more local (rather than landscape scale) level. Cycles of drought and flooding may also affect shoreline communities, access to geological assets and the overall look of the feature.

Historic landscape around the Isle of Axholme and north of Doncaster. Possible declines in hedgerow quality and increasing damage from deep rooted plants on historic assets may combine to give the Fishlake and Sykehouse landscape a more degraded feel, though changes in cropping patterns are more likely to impact on the overall ‘feel’ of the landscape. Given the uncertainty over changes in farming practice in response to climate change, it is hard to predict the extent to which the enclosed landscape will retain its status as a defining aspect of landscape character. The Isle of Axholme’s strip farming may also be vulnerable to changes in farming practice without continued incentive to retain historic field patterns.

Large geometric fields bounded by dykes and ditches, canals and altered river courses. The large geometric field boundaries are unlikely to change, and there is likely to be a heightened need for the drainage networks around fields. However, cropping patterns may well change with different crops being favoured as the climate changes, changing the texture of the landscape, though not its overall form. Water courses are likely to be highly vulnerable to climate change, as ditches, canals and river systems suffer significant stresses as the climate warms and dries during summer months. However, wetter winters are likely to drive demand for more efficient, managed and functional drainage of fields, with a consequent impact on the plant and animal communities that currently inhabit ditch systems. Therefore, while climate change is unlikely to impact significantly at the landscape scale, as field patterns remain largely intact, at a local level, the environmental quality and feel of field boundaries may be diminished.

Remnant heath, birch and oak woodlands alongside isolated conifer plantations. Hotter summers and consequent increases in tree stress, changes in pest species and elevated fire risk may leave native woodlands offering a diminished contribution to landscape character at the more local scale. However, at a landscape scale, at least in the near term, it is likely that woodlands will remain visible, albeit with a changing tree species composition. Tree species may change in plantation woodlands once they have been harvested, which may have a subtle influence on local level vistas (Forest Research 2010)[14]. However, if plantation woodlands are replaced by, for example biomass crops, the change will be more marked.

Settlements and roads are located on higher ground. The fact that many settlements are on higher ground is a function of the fact that historically land in the NCA has flooded (Scottish Natural Heritage, undated). Landscape is likely to be increasingly prone to flood events, thus this historic

[14] Forest Research has undertaken research into tree species vulnerability under climate change scenarios. For example, Corsican pine is the conifer species likely to benefit most from climate change, becoming the most productive species in more of the Humberhead Levels character area, assuming a 2050s ‘high’ emissions scenario (using UKCP climate profiles)

legacy is likely to make such settlements resilient to climate change. The character of such settlements may however change if higher ground is affected by an increased demand to locate new rural dwellings and employment sites outside of flood zones.

Isolated farmsteads, former monastic granges, specialist steadings and a high concentration of moated sites. These assets are unlikely to be significantly impacted by expected changes to climate, though, in common with other buildings, individual farmsteads, granges and steadings may be vulnerable to flood damage.

Ecosystem services

Food and biomass production. Climate change is likely to significantly affect agriculture in the NCA, both in terms of the direct impacts of increased soil erosion, drought stress on crops and threats arising from new pest species and crop and livestock diseases, but also in terms of the way in which the farming community deals with these impacts. For instance, the response of the agriculture sector to climate change may radically alter the landscape as new crops are grown, perhaps more onions and sweetcorn, two crops per year may be taken, or alternative livestock species preferred. However, the NCA is likely to continue to deliver a food production function, albeit through different farming methods or different foodstuffs. It is possible that biomass and wind energy production will increase in significance in the NCA with potentially more land being used for its production.

Freshwater provision and drainage. Changes in hydrology in the NCA as a result of climate change may make the freshwater provision service vulnerable. While climate change may not significantly affect the geology of the area which results in productive fissure flows, a reduction in the amount of rainfall received by the NCA may reduce these fissure flows. Similarly, flow rates in rivers from which water is extracted may be reduced during spells of drought, at the very time when demand for water increases. There may be an increased demand for summer irrigation.

Climate regulation. Soils store carbon, with soils such as peat with a high level of organic material storing the greatest proportion of carbon. The oxidation of peat, which can result from drying out, may lead to peat in the NCA releasing significant amounts of carbon, thus reducing the efficacy of this key ecosystem service. However, as peat often forms in marshy areas with anaerobic soil conditions wetter winters may result in higher water tables, creating suitable conditions for peat formation.

Flood water storage. There are large amounts of floodplain in the Character Area. Allowing space for water to be stored during flood events, for instance in flood meadows or through managed realignment schemes, helps ensure that settlements in the floodplain are less prone to flooding. Wetter winters may challenge the capacity of floodplain storage as it struggles to cope with the volume of water. However, as more floodplain acts as storage there may be benefits for biodiversity as certain species benefit from the availability of waterlogged land. Climate change is, therefore, likely to increase the need for this service, and consequently increase the amount of land required to deliver it.

Soil formation. Soil formation will be affected by drier summers and wetter winters. In particular soil formation is dependent on soil organisms. Summer desiccation and winter water logging is likely to reduce their activity. In addition, dry soils lead to soil loss (though erosion). There are however, some potentially positive effects of warmer, wetter winters in particular, with sediments from fluvial and tidal floodwaters increasing nutrient levels in soils, and warmer winters may increase nitrification and nitrate availability in soils, though the levels at which this is taken up by plants or leaches out of soils is uncertain.

Knowledge assets. A good deal of our historical record is found in the landscape. Drier summers, wetter winters and sea level rise all pose a threat, with assets such as the peat and pollen record potentially being impacted by drying and erosion of the peat surface. Sea level rise and flooding could lead to the loss of historical assets close to the Humber Estuary or in the floodplain. This would suggest that a number of knowledge assets within the NCA are vulnerable to climate change.

Recreation, health and wellbeing. The recreational value of the NCA may be enhanced by warmer temperatures throughout the year as more people are encouraged to use the natural environment as a recreational resource, but key assets such as footpaths may be damaged by wetter weather, combined with greater usage, during the winter months. The aesthetic value of the landscape may also change, and changes to key character features, such as canals and ponds may reduce people's motivation to utilise the NCA's recreational resource. There is therefore uncertainty over the overall effect of climate change on the recreational function; however, it is likely that maintaining the current levels of accessibility to the countryside will be increasingly resource intensive.

Pollination. Many pollinators are sensitive to changes in climate variables with changes in seasons potentially de-aligning the life cycles of pollinator species from the lifecycles of wildflower species for example. Changes in temperature, humidity and soil moisture may affect pollinator pathogens, while if summer rainfall declines increased exposure of pollinators to pesticides may occur.

Sense of place. Key features of the landscape such as the heathland and peatland wilderness may change considerably as a result of climate change, and winter flooding may fundamentally change the overall appearance of the winter landscape across large swathes of the Character Area. Other impacts, such as changing crop patterns and impacts on the historic environment may degrade the existing sense of place, though it could well be replaced by a modified perception of what defines the NCA.

Biodiversity

There are a number of vulnerable habitats and species identified in this study, with some of the most iconic habitats and species potentially vulnerable to the anticipated effects of climate change. While a number of species currently at their northern limit may prosper as a result of climate change if suitable habitat is available, it is likely that there will be a significant decline in the condition of lowland mires and a number of other wetland habitats in particular. This may mean that the area becomes less significant for biodiversity than it is today.

Although climate change may create opportunities for new habitats to develop, particularly in the floodplain (for example, new floodplain grazing marsh and fen), much will depend on how land is managed. In addition, some of the NCA's most 'iconic' species may be highly vulnerable to climate change, with recent conservation gains for species such as bittern highly vulnerable to loss of habitat due to phenomena such as sea level rise, pollution or drought episodes.

Appendix 3 Adaptation actions – adapting landscape character and ecosystem services

Actions to address vulnerability of landscape characteristics

The following landscape characteristics were not considered vulnerable to climate change and were, therefore, not considered further in this section:

- A low-lying area of the former pro-glacial Lake Humber often falling below the mean water level.
- Essentially flat, very open character with distant views and big skies, and occasional rising ground formed by ridges of sand and outcrops of Mercia Mudstone.
- Settlements and roads are located on higher ground.

Waterlogged archaeological remains and palaeo-environmental deposits of international importance in the Trent floodplains

- Measure and monitor all elements of the historic environment to enable a prioritised response.
- Where possible work with landowners to encourage entry into sympathetic land management agreements through environmental stewardship schemes.

Extensive floodplains, washlands, saltmarsh and traditionally grazed alluvial flood meadows (Ings) associated with navigable rivers

- Increased capacity of the catchment to retain rainfall runoff through 'naturalisation'.
- Investigate need for more strategic management including upstream water storage activity where consistent with landscape character.
- Target Higher Level Stewardship at these habitats to facilitate best practice management and extend the area of land managed as water dependant habitats where appropriate, for example flood meadows or salt marsh where appropriate.
- Manage washlands so that a variety of levels help to retain winter flood water for longer but also include some elevated ground as refuges for species vulnerable to inundation events.

The peat bogs and raised mires

- Increased resilience of habitat by working with stakeholders to reduce negative impacts of land use adjacent to the bog and create adjacent wetland.
- Maintain and enhance good water control measures at sites to maintain water levels.
- Ensure appropriate weight is given to rarity and status of peat bogs and raised mire habitat in flood management plans for the Humber.
- Develop emergency response plans to reduce fire risk.
- Continue to undertake bog restoration activity.

Rich and fertile farmland

- Retain water level management engineering assets where they protect a proportion of the best and most versatile land and do not compromise wider environmental goals.

- Encourage good land management practice which helps to help retain and improve soil structure, water retention capacity (where appropriate), and reduce erosion.
- Protect water courses from chemical and nutrient runoff from farmland with features such as buffer strips and good land management practice.

Small areas of Carr woodland and rare alder woodland

- Maintain existing habitat through maintaining water levels where possible.
- Increase permeability of landscape between woodland sites so that species exchange can occur, including through targeting incentives for short rotation coppice.
- Explore potential for habitat creation, for instance along stream and rivers or on flood storage land.
- Investigate threats from pests and diseases.

Flooded gravel pits and subsidence flashes

- Increase ecosystem resilience by buffering water bodies from ingress of pollutants and sediments and promote management of non-native species.
- Create more pools as part of sustainable drainage schemes and in management of washlands / flood meadows.
- Restore structural diversity in water bodies.
- Ensure that management plans for gravel pits maintain geological interest assets where possible.
- Consider after use of gravel extraction sites through the planning system.
- Consider the extension of SSSI / RIGS boundaries where gravel pits of geological interest become flooded.
- Ensure licensing regimes effectively regulate water abstractions at a sustainable level.

Historic landscape around the Isle of Axholme and north of Doncaster

- Measure and monitor all elements of the historic environment to gain a fuller understanding of the resource and to enable prioritisation.
- Target appropriate Environmental Stewardship options to help protect key assets.
- Carry out research into hedgerow management, including provenances of hedgerow species.
- Continue to support strip farming on the Isle of Axholme through use of agri-environment schemes.

Large geometric fields bounded by dykes and ditches, canals and altered river courses

- Retain water level management engineering assets
- Promote soil conservation measure and buffer watercourse.

Remnant heath, birch and oak woodlands alongside large isolated conifer plantations

- Ensure appropriate management to maintain heaths (for example, adaptive grazing management).
- Reduce fire risk through education and working with fire agency.
- Enhance ‘permeability’ of landscape between key sites so species exchange can occur.
- Research and promote resilient species for plantation woodlands.

Isolated farmsteads, former monastic granges, specialist steadings, and high concentration of moated sites

- Measure and monitor elements of the historic environment potentially affected by climate change to enable a prioritised response.
- Modify buildings in environmentally sensitive ways to cope better with future weather conditions.

Actions to address vulnerability of ecosystem services

Food and biomass production

- Carry out research into appropriate new crops and better information and better guidance.
- Monitor pests, diseases and pollinators.
- Retain water management engineering assets.
- Promote greater on-farm water storage, sensitive to landscape character.
- Promote good soil management to address issues including erosion and soil water deficit and flood events where appropriate and consistent with wider landscape objectives.
- Where environmental constraints allow, direct biomass fuel production to poor quality land (excluding wetlands).

Freshwater provision and drainage

- Increased capacity of the catchment to retain rainfall through 'naturalisation'.
- Promote demand management and water conservation.
- Promote on-farm water management and storage, integrating biodiversity into the design of reservoirs whenever possible.
- Invest in low-water demanding technologies, including more drought resistant crops.
- Investigate need for more strategic management including upstream water storage activity where appropriate.
- Encourage the raising of the water table level and the creation of wetland habitats where appropriate.

Climate regulation

- Maintain the Thorne and Hatfield Moors improvement activities, and rollout practice/processes to other sites.
- Incorporate visitor management strategies where/if necessary.
- Develop emergency response plans for areas vulnerable to fire risk.

Flood water storage

- Increased capacity of the catchment to retain rainfall through 'naturalisation'.
- Investigate need for more strategic management including upstream water storage activity, using opportunities to create habitats around water storage features where appropriate.
- Where suitable, expand intertidal habitats around Humber Estuary to offset coastal squeeze and increase sustainability of flood defences elsewhere.

Soil formation

- Address soil loss through promoting effective erosion control.
- Promote measures to address soil water deficit, such as increasing the organic content of soils (where appropriate) and increasing amount of sympathetically designed on-site water storage.

- Maintain drainage systems to avoid water logging in productive areas where the primary landscape function is food production. Ensure biodiversity interest is not negatively affected by drainage.

Knowledge assets

- Measure and monitor elements of the historic environment vulnerable to climate change to enable a prioritised response.
- Where possible work with landowners to encourage entry into sympathetic land management agreements through environmental stewardship schemes.
- Encourage the raising of the water table levels, especially in peaty soils, to protect palaeo-environmental evidence.

Recreation

- Greater and enhanced maintenance regime and higher construction standards leading to greater resilience of pathways.
- Educate countryside users about sensible use, such as bringing water on walks and how to reduce fire risk.
- Incorporate visitor management strategies on key sites where necessary.
- Develop emergency response plans for the peatland areas.

Pollination

- Increase range of micro climates at a local scale through site management.
- Monitor pollinator populations.

Health and wellbeing

- Prioritise maintenance of rights of way and accessible green space close to settlements.

Sense of place

- Implement actions to ensure key iconic habitats, such peatlands and watercourses are resilient to climate change.
- Work to retain distinctive landscapes, such as around the Isle of Axholme, through targeting environmental stewardship.

Aesthetic value

- Take opportunities to ensure that new development enhances local landscape character.

Actions to address vulnerability of biodiversity

- Identify sites most at risk from climate change impacts such as damage due to poor water quality.
- Work with landowners adjacent to important wildlife site to ensure that pollutant input and disruption of hydrological regime is minimised.
- Increase the ability of river catchments to retain rainfall and moderate flow.
- Restore riparian shading in places to reduce effects of heat stress on aquatic organisms.
- Balance the need for ditch management to be effective as a drainage system with retention of biodiversity interest (for example, by taking a phased approach to clearing of ditches, or by clearing one side at a time).
- Increase the connectivity / permeability between semi-natural habitats across the landscape.

- Reduce pressure from non native species by appropriate management and education.
- Manage habitats to increase structural diversity and microclimates (for example, create pools of different depths in wetlands).
- Encourage appropriate adaptive management through incentives such as environmental stewardship.
- Reduce sources of external stress to allow development of healthier habitats more able to cope with additional stresses imposed by climate change.

Appendix 4 Adaptation assessment screening matrix

Table G Adaptation assessment screening matrix

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
STRATEGIC ACTIONS								
Catchment scale adaptation	✓	✓	✓	✓	0 ✓	✓	0	0
Take a landscape-scale approach to managing and creating habitat	✓	✓	✓	✓	0 ✓	✓	0	0
Build climate change into the spatial planning agenda	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Development of multifunctional wetlands, where appropriate	✓	✓	✓	✓	+/-	✓	✓	✓
Understanding and responding to land use change	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Build partnerships with a broad stakeholder base	✓	✓	✓	✓	+/-	✓	✓	✓
Public awareness and understanding of impacts of climate change	✓	✓	0	0	0 0	✓	0	✓

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Monitoring	✓	✓	✓	✓	✓ ✓	✓	✓	✓
ADAPTATION ACTIONS PROPOSED FOR THE KEY CHARACTERISTICS OF THE NCA								
Waterlogged archaeological remains and palaeo-environmental deposits of international importance in the Trent floodplains								
Measure and monitor all elements of the historic environment vulnerable to climate change to enable a prioritised response	0	0	0	0	0 0	0	✓	0
Where possible work with landowners to encourage entry into sympathetic land management agreements through environmental stewardship schemes	✓	✓	✓	✓	0 ✓	✓	✓	✓
Extensive floodplains, washlands, saltmarsh and traditionally grazed alluvial flood meadows (Ings) associated with navigable rivers								
Increased capacity of the catchment to retain rainfall through ‘naturalisation’	✓	✓	✓	✓	0 ✓	✓	0	0
Investigate need for more strategic management including upstream water storage activity where consistent with landscape character	✓	✓	+/-	✓	0 ✓	✓	0	0
Target Higher Level Stewardship at these habitats to facilitate best practice management and extend the area of land managed as water dependant habitats where appropriate, for example flood	✓	✓	✓	✓	0 ±	✓	+/-	0
Manage washlands so that a variety of levels help to retain winter flood water for longer but also include some elevated ground as refuges for species vulnerable to inundation events	✓	✓	0	✓	0 0	✓	0	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
The peat bogs and raised mires								
Increased resilience of habitat by working with stakeholders to reduce negative impacts of land use adjacent to the bog and create adjacent wetland	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Maintain good water control measures at sites to maintain water levels	✓	✓	✓	✓	✓ ✓	✓	✓	0
Ensure appropriate weight is given to rarity and status of peat bogs and raised mire habitat in flood management plans for the Humber	0	0	✓	✓	✓ ✓	✓	✓	✓
Develop emergency response plans to reduce fire risk	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Continue to undertake bog restoration activity	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Rich and fertile farmland								
Retain water level management engineering assets where they protect a proportion of best and most versatile land and do not compromise wider environmental goals	0	0	0	✓	0 ✓	+/-	0	0
Encourage good land management practice, consistent with landscape character, which helps to help retain and improve soil structure, water retention capacity (where appropriate), and reduce	✓	✓	+/-	✓	0 ✓	✓	0	0
Protect water courses from chemical and nutrient runoff from farmland with features such as buffer strips and good land management practice	✓	✓	0	✓	0 ✓	✓	0	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Small areas of carr woodland and rare alder woodland								
Maintain existing habitat through maintaining water levels where possible	✓	✓	✓	✓	0 0	✓	0	0
Increase permeability of landscape between woodland sites so that species exchange can occur, including through targeting incentives for short rotation coppice	✓	✓	✓	✓	0 0	✓	0	0
Explore potential for habitat creation, for instance along stream and rivers or on flood storage land	✓	✓	✓	✓	0 0	✓	0	0
Investigate threats from pests and diseases	✓	✓	0	✓	0 0	✓	0	0
Flooded gravel pits and subsidence flashes								
Increase ecosystem resilience by buffering ponds and gravel pits from ingress of pollutants and sediments and promote management of non-native species	✓	✓	0	✓	✓ 0	✓	0	✓
Create more pools as part of sustainable drainage schemes and in management of washlands / floodmeadows	✓	✓	✓	✓	0 ✓	✓	0	0
Restore structural diversity in water bodies	✓	✓	0	✓	0 0	✓	0	0
Ensure that management plans for gravel pits maintain geological interest features where possible	✓	✓	0	✓	✓ 0	0	0	0
Consider after use of gravel extraction sites through the planning system for biodiversity and geological diversity	✓	✓	✓	✓	0 +/-	✓	0	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Consider the extension of SSSI / RIGS boundaries where gravel pits of geological interest become flooded	0	✓	0	✓	✓ 0	0	0	0
Ensure licensing regimes effectively regulate water abstractions at a sustainable level	✓	✓	✓	✓	0 0	✓	0	0
Historic landscape around the Isle of Axholme and north of Doncaster								
Measure and monitor all elements of the historic environment to gain a fuller understanding of the resource and to enable prioritisation	0	✓	✓	✓	0 0	✓	✓	0
Target appropriate Environmental Stewardship options to help protect key features	✓	0	✓	✓	0 ✓	✓	✓	0
Carry out research into hedgerow management, including provenances of hedgerow species	0	0	✓	0	0 0	✓	✓	0
Continue to support strip farming on the Isle of Axholme through the use of agri-environment schemes	0	✓	✓	0	0 ✓	0	✓	0
Large geometric fields bounded by dykes and ditches, canals and altered river courses								
Retain water level management engineering assets	0	✓	✓	✓	0 ✓	0	✓	0
Promote soil conservation measure and buffer watercourse	✓	✓	✓	✓	0 ✓	✓	0	0
Remnant heath, birch and oak woodlands alongside large isolated conifer plantations								

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Ensure appropriate management to maintain heaths (for example, adaptive grazing management)	✓	✓	✓	✓	0 0	✓	✓	✓
Reduce fire risk through education and working with fire agency	✓	✓	✓	✓	0 0	✓	✓	✓
Enhance 'permeability' of landscape between key sites so species exchange can occur	✓	✓	✓	✓	0 0	✓	0	0
Research and promote resilient species for plantation woodlands	0	+/-	+/-	✓	0 0	+/-	0	0
Isolated farmsteads, former monastic granges, specialist steadings, and high concentration of moated sites								
Measure and monitor elements of the historic environment potentially affected by climate change to enable a prioritised response	0	✓	0	✓	0 0	0	✓	0
Modify buildings in environmentally sensitive ways to cope better with future weather conditions	0	✓	+/-	0	0 0	+/-	+/-	0
ADAPTATION ACTIONS PROPOSED FOR ECOSYSTEM SERVICES PERFORMED BY THE NCA								
Food and biomass production								
Cary out research into appropriate new crops and better information and better guidance	✓	✓	0	✓	0 ✓	0	0	0
Monitor pests, diseases and pollinators	✓	✓	0	✓	0 0	✓	0	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Retain water management engineering assets	0	✓	0	0	0 ✓	0	✓	0
Promote greater on-farm water storage, sensitive to landscape character	✓	✓	0	✓	0 0	✓	0	0
Promote good soil management to address issues including erosion and soil water deficit and flood events, where appropriate and consistent with wider landscape objectives	✓	✓	+/-	✓	0 ✓	✓	0	0
Where environmental constraints allow, direct biomass to poor quality land	✓	✓	+/-	+/-	0 ✓	+/-	0	0
Freshwater provision and drainage								
Increased capacity of the catchment to retain rainfall through ‘naturalisation’	✓	✓	✓	✓	0 ✓	✓	0	0
Promote demand management and water conservation	✓	✓	✓	✓	0 ✓	0	0	0
Promote on farm water management and storage, integrating biodiversity into the design of reservoirs whenever possible	✓	✓	0	✓	0 ✓	✓	0	0
Invest in low-water demanding technologies, including more drought resistant crops	✓	✓	0	✓	0 ✓	✓	0	0
Investigate need for more strategic management including upstream water storage activity, where appropriate	✓	✓	+/-	✓	0 ✓	✓	0	0
Encourage the raising of the water table and creation of wetland habitats where appropriate	+/-	+/-	✓	+/-	+/-	✓	+/-	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Minerals								
Ensure impacts of climate change are considered and addressed through the site aftercare objectives and management plans, and that wider considerations are incorporated where possible and appropriate	✓	✓	✓	✓	✓	✓	✓	✓
Climate regulation								
Maintain the Thorne and Hatfield Moors improvement activities, and rollout practice/processes to other sites	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Incorporate visitor management strategies where/if necessary	✓	✓	✓	✓	0 0	✓	✓	✓
Develop emergency response plans for the moorland areas	-	✓	✓	✓	✓ 0	✓	✓	✓
Flood water storage								
Increased capacity of the catchment to retain rainfall through 'naturalisation'	✓	✓	✓	✓	0 ✓	✓	0	0
Investigate need for more strategic management including upstream water storage activity , using opportunities to create habitats around water storage features where appropriate	✓	✓	+/-	✓	0 ✓	✓	0	0
Where suitable expand intertidal habitats around Humber Estuary to offset coastal squeeze and increase sustainability of flood defences elsewhere	✓	✓	✓	✓	0 +/-	✓	+/-	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Soil formation								
Address soil loss through promoting effective erosion control	✓	✓	0	✓	0 ✓	✓	✓	0
Promote measures to address soil water deficit, such as increasing the organic content of soils (where appropriate) and increasing amount of sympathetically designed on-site water storage	✓	✓	+/-	✓	0 ✓	✓	✓	0
Maintain drainage systems to avoid water logging in productive areas where the primary ecosystem service is food production. Ensure biodiversity interest is not negatively affected by drainage	✓	✓	✓	✓	0 ✓	+/-	✓	0
Knowledge assets								
Measure and monitor elements of the historic environment vulnerable to climate change to enable a prioritised response	0	✓	0	0	0 0	0	✓	0
Where possible work with landowners to encourage entry into sympathetic land management agreements through environmental stewardship schemes	✓	✓	✓	✓	0 ✓	✓	✓	0
Encourage the raising of water table levels, especially in peaty soils, to protect palaeo-environmental evidence	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Recreation								
Greater and enhanced maintenance regime and higher construction standards leading to greater resilience of pathways	✓	✓	0	✓	0 ✓	✓	0	✓
Educate countryside users about sensible use, such as bringing water on walks and how to reduce fire risk	✓	✓	✓	✓	0 ✓	✓	0	✓

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Incorporate visitor management strategies on key sites where necessary	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Develop emergency response plans for the peatland areas	-	✓	✓	✓	✓ ✓	✓	✓	✓
Pollination								
Increase range of micro climates at a local scale through site management	✓	✓	0	0	0 0	✓	0	0
Monitor pollinator populations	✓	✓	✓	✓	0 0	✓	0	0
Health and wellbeing								
Prioritise maintenance of rights of way and accessible green space close to settlements	✓	✓	0	✓	0 0	0	0	✓
Sense of place								
Implement actions to ensure key iconic habitats, such as peatlands and watercourses are resilient to climate change	✓	✓	✓	✓	✓ ✓	✓	✓	✓
Work to retain distinctive landscapes, such as around the Isle of Axholme, through targeting environmental stewardship	✓	✓	✓	✓	0 ✓	✓	✓	✓

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils		Habitats and species	Historic environment	Access & recreation
Aesthetic value									
Take opportunities to ensure that new development enhances local landscape character	✓	✓	✓	✓	0	0	0	0	0
Adaptation actions proposed for biodiversity									
Identify sites most at risk from climate change impacts such as damage due to poor water quality	✓	0	0	✓	0	0	✓	0	0
Work with landowners adjacent to important wildlife sites to ensure that pollutant input and disruption of hydrological regime is minimised	✓	✓	✓	✓	0	0	✓	0	0
Increase the ability of river catchments to retain rainfall and moderate flow	✓	✓	✓	✓	0	✓	✓	0	0
Restore riparian shading in places to reduce effects of heat stress on aquatic organisms	✓	✓	✓	✓	0	0	✓	0	✓
Balance the need for ditch management to be effective as a drainage system with retention of biodiversity interest (for example by taking a phased approach to clearing of ditches, or by clearing	✓	✓	✓	✓	0	✓	✓	0	0
Increase the connectivity / permeability between semi-natural habitats across the landscape	✓	✓	✓	✓	0	0	✓	0	✓
Reduce pressure from non native species by appropriate management and education	✓	✓	0	✓	0	0	✓	0	0
Manage habitats to increase structural diversity and microclimates (for example, create pools of different depths in wetlands)	✓	✓	✓	✓	0	0	✓	0	0

Table continued…

Action	Win-win	Low regrets	Landscape character	Ecosystem services	Geology & soils	Habitats and species	Historic environment	Access & recreation
Encourage appropriate adaptive management through incentives such as environmental stewardship	✓	✓	✓	✓	0 0	✓	0	0
Reduce sources of external stress to allow development of healthier habitats more able to cope with additional stresses imposed by climate change	✓	✓	0	✓	0 0	✓	0	0

Key:

✓	**Action will have a positive effect on the column category**
0	Action will not affect the category
-	Action will have a negative effect on the column category
+/-	The action’s effect could be positive or negative, depending on the way it is executed

Appendix 5 Organisations represented at workshops

Workshop 1: 21 January 2010

- Country Land and Business Association
- Doncaster Council
- English Heritage
- Environment Agency
- Isle of Axholme Drainage Board[15]
- National Farmers Union
- Natural England
- North Lincolnshire Council
- RSPB
- Selby District Council
- Woodland Trust
- Yorkshire Wildlife Trust

Workshop 2: 10 February 2010

- This workshop involved the members of the Humberhead Levels Partnership

[15] Now known as the Isle of Axholme and North Nottinghamshire Water Level Management Board

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

www.naturalengland.org.uk