Character Area Climate Change Project NE114R

Responding to the impacts of climate change on the natural environment: The Broads

First published 31 March 2009

www.naturalengland.org.uk

NATURAL ENGLAND

The Broads

© Natural England (Mike Page)

Hickling Broad and the Upper Thurne

Natural England Project Manager - Andy Neale, Natural England, John Dower House, Crescent Place, Cheltenham, GL50 3RA

Natural England Local Contact - Clive Doarks, Natural England, Dragonfly House, 2 Gilders Way, Norwich, Norfolk, NR3 1UB

Keywords - Climate Change, Character Areas, biodiversity, landscape

Further information
This report can be downloaded from the Natural England website: **www.naturalengland.org.uk**. For information on Natural England publications contact the Natural England Enquiry Service on 0845 600 3078 or e-mail **enquiries@naturalengland.org.uk**

Summary

Introduction

Natural England is working to deliver a natural environment that is healthy, enjoyed by people and used in a sustainable manner. However, the natural environment is changing as a consequence of human activities, and one of the major challenges ahead is climate change. Even the most optimistic predictions show us locked into at least 50 years of unstable climate. Changes in temperature, rainfall, sea levels, and the magnitude and frequency of extreme weather events will have a direct impact on the natural environment. Indirect impacts will also arise as society adapts to climate change. These impacts may create both opportunities and threats to the natural environment. Natural England and its partners therefore need to plan ahead to secure the future of the natural environment. One way in which we are doing this is through the Character Area Climate Change Project.

The project aims to identify the local responses required to safeguard the natural environment and our enjoyment of it. In the pilot phase we are focussing on four of the 159 'Character Areas' in England, one of which is the Broads. The others are the Shropshire Hills, Cumbria High Fells, and Dorset Downs and Cranbourne Chase.

This report provides the detailed findings from the pilot project. The summary leaflet is also available on our website at www.naturalengland.org.uk. It:

- identifies significant biodiversity, landscape, recreational and historic environment assets;
- assesses the potential risks climate change poses to these assets; and
- suggests practical actions that would make them more resilient to the impacts of climate change.

What we learn from the four pilot projects will be used to extend the approach across England as part of our aim to build a healthy and resilient natural environment for the future. Although the project is primarily concerned with the natural environment, it has also considered the impacts of climate change on other areas of Natural England's remit, including access and recreation, landscape, and the historic environment.

About this project

The objective of the Character Area Climate Change Project is to ensure that when decisions on the future of places like the Broads are made, proper account is taken of impacts on the natural world, as well as on communities and their livelihoods. It is not Natural England's role, or intention, to take such decisions, but to initiate debate on the impacts of climate change on the natural world, so that well informed decisions about its future can be taken.

Flood management has a critically important part to play in the future of the Broads. Natural England will continue to work with all relevant authorities to explore the best long term approach. Communities and their livelihoods are vital considerations in the development of any future strategy to respond to climate change. This report does not attempt to cover these issues, not because they are unimportant, but because Natural England's role is primarily in relation to the natural environment. In producing this report, Natural England is acutely aware of the need for a socially just approach and the need for adequate tools and resources to enable communities to adapt to climate change. Ensuring a strong, healthy, diverse and inclusive society that lives within environmental limits is the key objective of sustainable development. Natural England

seeks to contribute to this through its management of the natural environment. We recognise that environmental and social solutions need to proceed in tandem. Informed by this project, we will engage with communities, other organisations and Government to find approaches that deliver successful and long-term adaptation to climate change.

The challenges presented by climate change are significant, and nowhere more so than the Broads. Time is required to consider the range of impacts on all aspects of society and to develop integrated responses. Taking action to respond to climate change will also depend on the cooperation of those who own and manage the land. We do not take that cooperation for granted and are aware that many measures will require appropriate incentives. At this stage we wish to explore with others potential responses which are feasible and acceptable in principle, and have not yet considered the detailed mechanisms of change.

Significant natural assets

The Broads Character Area is a low-lying area on the eastern edge of East Anglia, between Norwich and the North Sea coast. Its boundary roughly follows the edge of the floodplain of the rivers Yare, Waveney and Bure and its tributaries, the Ant and the Thurne. As well as the flat floodplain the pilot area also takes in the valley sides. Much of the Broads is open country with few urbanised areas. Large parts of the floodplain are in grazing agriculture; however there are extensive areas of wet woodland and fen habitats in the middle valley reaches.

The Broads is one of Europe’s finest and most important wetland areas. The most significant biodiversity assets found in the Broads include:

- open water bodies;
- freshwater wetland habitats;
- coastal habitats;
- lowland habitats;
- internationally important numbers of wintering wildfowl and wetland birds; and
- nationally important invertebrate and plant assemblages.

The Broads has the largest expanse of species-rich fen in lowland Britain, while more than 200 species of invertebrate have been recorded from its drainage ditches. A number of iconic species are present in the Broads including the swallowtail butterfly, Norfolk hawker dragonfly, European crane and the bittern.

To many people the flat, open, wet landscape of the Broads is iconic. Over half of the Character Area forms the Broads nationally protected landscape, equivalent to a National Park. In addition, a small part of the Norfolk Coast Area of Outstanding Natural Beauty overlaps the area.

The most significant landscape assets include:

- broads and rivers and other shallow open water bodies;
- carr woodland;
- drained peat and peat clay mix;
- estuary;
- heathland;
- dune and coastal levels;
- estuarine marshland; and
- grazing marsh and fen.

It is also recognised that the area has a significant archaeological and built heritage interest. Approximately 250 buildings within the pilot area are listed. There are 74 surviving drainage mills and 13 ancient monuments. A number of important geodiversity sites are also present.

The Character Area is an attractive and popular destination for visitors, with a rich array of significant access and recreation assets. The Broads is one of the most extensive waterway systems in the UK, offering 190 km of boating on lock-free tidal rivers and a significant fleet of private and hire boats. Specialist pike angling is particularly significant in the Broads and angling for coarse fish such as bream, eel, perch, pike, rudd and tench is very popular. Cycling is increasingly important in the Broads and National Route 1 and Regional Route 30 pass through the area. The area also has a varied rights of way network, sandy beaches and sand dunes and interesting historic buildings and settlements.

The most significant ecosystem services provided by the Broads, from which we all benefit, include:

- water resources and water quality;
- provision of food and recreation;
- tourism and education;
- flood protection; and
- climate regulation.

Likely impacts of climate change on the Broads

Evidence from the UK Climate Impacts Programme (2002) shows that the climate in the Broads over the coming century is likely to become warmer and wetter in winter and hotter and drier in summer, while sea levels will rise. In addition, rainfall intensity will probably increase. Extreme events such as heat waves and storms are predicted to increase in frequency and severity.

If no action is taken the most significant impacts of climate change on the Broads will be:

- an increase in the area of coastal and saline habitats;
- a reduction in the area of freshwater habitats;
- an increase in the frequency and duration of salt water ingress;
- damage to wetland habitats from repeated flooding and drought;
- loss of some species of animals and plants currently present in the Broads;
- the arrival of new animal and plant species, including non-native and invasive species.

Changes in temperature will affect the timing of periodic phenomena such as flowering, breeding and migration, which are likely to affect species' populations and habitat composition.

Further impacts will be:

- reduced water quality and increased saline penetration, with impacts on fish and angling;
- increased erosion;
- arrival of new pests and diseases;
- poorer air quality;

- reduced summer water levels in lakes and rivers, with impacts on plants and animals and also on recreation;
- algal blooms in broads and rivers;
- increased need for waterway management;
- greater visitor numbers;
- changes in the appearance of the landscape and historic features; and
- a reduction in the water resources available.

It is important to remember that climate change will not be the only change over the coming century. Changes in farming systems, the economy, population patterns and cultural values will also affect the natural environment of the Broads. Indeed climate change may have a greater impact on biodiversity through changes in agriculture than through direct biophysical impacts. Population growth in the East of England is likely to put further pressure on the area as demand for housing, recreation, transport and other infrastructure increases. Further development of wind power could impact on the landscape of the Broads. Our project does not try to assess these, although they will have significant implications for the area and any proposed adaptation measures.

Adaptation

The scale of the potential impacts in the Broads, in relation to its coastal nature and generally flat landscape, means that it is particularly vulnerable to the impacts of climate change. Responding to the impacts of climate change will require adaptation to prevent the natural environmental assets and the social and economic benefits that they provide from being lost.

In the short term there are some immediate actions that we can take to increase the resilience of existing features to climate change.

Based on the likely climate change impacts, a list of adaptation responses for the Broads has been compiled. These have been informed by the Defra guidelines for ‘conserving biodiversity in a changing climate’. These guidelines provide a sound basis for implementing climate change adaptation in the Broads for at least the short term, and in the majority of instances probably into the medium term and beyond. It is critically important that efforts are maintained to continue to restore, maintain and enhance the natural environment of the Broads, thereby making them more resilient to future change.

It should be noted that there may be policy, economic or other constraints to the delivery of some adaptation responses. Additionally, some of the actions identified may not have a delivery mechanism at present. The following adaptation responses are pertinent to the Broads.

- Maintain the quality of existing habitats: alter the timing and duration of grazing; alter the hay cutting date; reduce agricultural intensity on grazing marshes; create new wetland to moderate flooding of existing wildlife sites.

- Adapt dredging depths throughout the rivers to moderate saline intrusion; and create fish refuges.

- Bring existing habitats and species into a healthy state and conserve them for the future by appropriate management so they are resilient to climate change: undertake floodplain planting of wet woodland; restore water meadows and introduce permeable surfaces.

- Restore the structure and function of river channels; reduce sediment loading through catchment-sensitive farming; block coastal drains and raise water levels in the Upper Thurne to reduce saline ingress; and restore connectivity between river channels, their floodplains and wetland habitats.

- Extend existing habitats and create new areas. There may be limited opportunities in the Broads to recreate freshwater habitats as the area of suitable climate space declines; this will have to be elsewhere. However, there will be significant scope within the Broads to create brackish, transition and inter-tidal habitats.

- Monitor and plan for future potential catastrophic events such as storms or pests and diseases that may occur as a result of, or be exacerbated by, climate change.

- Assess the likely increase in visitor numbers and identify areas most at risk from the negative impacts of recreation. Provide shade and drinking water at tourist attractions and if necessary, place restrictions on water based recreation during periods of poor water quality.

- Use the spatial planning system to maintain adequate land for the natural environment, and identify research needs and commission appropriate studies to increase the effectiveness of strategies when implemented.

In the longer term, there are difficult issues that will need to be considered in relation to the potential climate change impacts for this area. A great deal of further work is required to fully understand the detailed social and economic implications of climate change and the adaptation responses that could help to respond to the impacts. Flood risk management has a critically important part to play in the future of the Broads and the Shoreline Management Plan and the Broads Flood Alleviation Strategy form the mechanisms for the exploration of possible future flood risk management options. The preferred policy option in the current draft of the Shoreline Management Plan (SMP) is to maintain the flood defences which stop the sea encroaching into the low lying parts of the Broads for at least the next 50 years. Natural England supports this policy and will continue to work with all relevant authorities and stakeholders to explore the best long term approach.

Next steps

This project on how climate change could affect the natural environment of the Broads Character Area, and the adaptation responses required, is a significant first step but cannot be conclusive. It provides an indication of what may happen. However, the future impacts of climate change are still uncertain and are partly dependent on the amount of greenhouse gases that society releases and how much is released by natural feedback loops from the environment (one of our biggest unknowns).

The long-term future for the Broads presents challenges given the potential impact of climate change. This project starts to identify the impacts and potential responses from an environmental perspective. These cannot be considered or implemented in isolation and Natural England believes that integrated solutions are required. In parallel with the short-term actions referred to above, Natural England will focus its attention on working with communities, Government and other stakeholders to ensure that policies and tools are put in place that enable successful adaptation to climate change, securing a future for the economy, people and environment of the Broads.

When identifying adaptation responses, existing strategies, policies and initiatives need to be considered. Some actions defined as climate change adaptation are already occurring under a different name and it may be possible to modify existing programmes to provide a mechanism for delivering adaptation. An example of this is the planned incorporation of climate change adaptation into Natural England's Environmental Stewardship Scheme.

Natural England will be using this report to work with partners to refine the detail, seek consensus and implement the adaptation actions identified within the report.

Natural England is now working on the following:

- An implementation plan for the possible adaptation responses, which may include a demonstration project. Natural England will work in partnership with local stakeholders to ensure that this builds upon and dovetails with other initiatives:

- Providing ongoing input and support to the Shoreline Management Plan process and the Broads Authority led Broads Climate Change Adaptation Panel:

- Learning from the pilot process to assess likely climate change impacts and the possible adaptation strategies for other Character Areas both regionally and nationally:

The future of the Broads depends on the actions we all take today to reduce our greenhouse gas emissions. This, combined with decisions we make about managing our landscapes to adapt to unavoidable climate change, will determine whether we continue to have a high-quality landscape that is cherished and respected by all.

Technical report

Contents

Glossary of Terms

AOD	Above Ordnance Datum
AONB	Area of Outstanding Natural Beauty
BAP	Biodiversity Action Plan
BESL	Broadland Environmental Services Limited
CHaMP	Coastal Habitat Management Plan
CROW	Countryside and Rights of Way
EHN	England Habitat Network
GCM	General Circulation Model
GHG	Greenhouse gas
HAP	Habitat Action Plan
HPA	Health Protection Agency
IDB	Internal Drainage Board
IPCC	Inter Governmental Panel on Climate Change
MEA	Millennium Ecosystem Assessment
NGO	Non-Governmental Organisation
NVC	National Vegetation Classification
POST	Parliamentary Office of Science and Technology
RCM	Regional Climate Model
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest
SPA	Special Protection Area
SRES	Special Report on Emissions Scenarios
SUDS	Sustainable Urban Drainage Systems
UKCCP	United Kingdom Climate Change Programme
UKCIP	United Kingdom Climate Impacts Programme
UNEP	United Nations Environment Programme

1. Introduction

1.1 Foreword

Natural England is working to deliver a natural environment that is healthy, enjoyed by people and used in a sustainable manner. However, the natural environment is changing as a consequence of human activities, and one of the major challenges ahead is climate change. Even the most optimistic predictions show us locked into at least 50 years of unstable climate. Changes in temperature, rainfall, sea levels, and the magnitude and frequency of extreme weather events will have a direct impact on the natural environment. Indirect impacts will also arise as society adapts to climate change. These impacts may create both opportunities and threats to the natural environment. Natural England and its partners therefore need to plan ahead to secure the future of the natural environment. One way in which we are doing this is through the Character Area Climate Change Project.

The project aims to identify the local responses required to safeguard the natural environment and our enjoyment of it. In the pilot phase we are focussing on four of the 159 ‘Character Areas’ in England, one of which is the Broads. The others are the Shropshire Hills, Cumbria High Fells, and Dorset Downs and Cranbourne Chase.

This report:

- identifies significant biodiversity, landscape, recreational and historic environment assets;
- assesses the potential risks climate change poses to these assets; and
- suggests practical actions that would make them more resilient to the impacts of climate change.

What we learn from the four pilot projects will be used to extend the approach across England as part of our aim to build a healthy and resilient natural environment for the future. Although the project is primarily concerned with the natural environment, it has also considered the impacts of climate change on other areas of Natural England's remit, including access and recreation, landscape, and the historic environment.

The objective of the Character Area Climate Change Project is to ensure that when decisions on the future of places like the Broads are made, proper account is taken of impacts on the natural world, as well as on communities and their livelihoods. It is not Natural England’s role, or intention, to take such decisions, but to initiate debate on the impacts of climate change on the natural world, so that well informed decisions about its future can be taken.

Flood risk management has a critically important part to play in the future of the Broads and the Shoreline Management Plan and the Broads Flood Alleviation Strategy form the mechanisms for the exploration of possible future flood risk management options. The preferred policy option in the current draft of the Shoreline Management Plan (SMP) is to maintain the flood defences which stop the sea encroaching into the low lying parts of the Broads for at least the next 50 years. Natural England supports this policy and will continue to work with all relevant authorities and stakeholders to explore the best long term approach.

Communities and their livelihoods are vital considerations in the development of any future strategy to respond to climate change. This report does not attempt to cover these issues, not because they are unimportant, but because Natural England's role is primarily in relation to the natural environment. In producing this report, Natural England is acutely aware of the need for a socially just approach and the need for adequate tools and resources to enable communities to adapt to climate change. Ensuring a strong, healthy, diverse and inclusive society that lives within environmental limits is the key objective of sustainable development. Natural England seeks to contribute to this through its management of the natural environment. We recognise that environmental and social solutions need to proceed in tandem. Informed by this project, we will engage with communities, other organisations and Government to find approaches that deliver successful and long-term adaptation to climate change.

The challenges presented by climate change are significant, and nowhere more so than the Broads. Time is required to consider the range of impacts on all aspects of society and to develop integrated responses. Taking action to respond to climate change will also depend on the cooperation of those who own and manage the land. We do not take that cooperation for granted and are aware that many measures will require appropriate incentives. At this stage we wish to explore with others potential responses which are feasible and acceptable in principle, and have not yet considered the detailed mechanisms of change.

1.2 Next steps

This project on how climate change could affect the natural environment of the Broads Character Area, and the adaptation responses required, is a significant first step but cannot be conclusive. It provides an indication of what may happen. However, the future impacts of climate change are still uncertain and are partly dependent on the amount of greenhouse gases that society releases and how much is released by natural feedback loops from the environment (one of our biggest unknowns).

The long-term future for the Broads presents challenges given the potential impact of climate change. This project starts to identify the impacts and potential responses from an environmental perspective. These cannot be considered or implemented in isolation and Natural England believes that integrated solutions are required. In parallel with the short-term actions referred to above, Natural England will focus its attention on working with communities, Government and other stakeholders to ensure that policies and tools are put in place that enable successful adaptation to climate change, securing a future for the economy, people and environment of the Broads.

When identifying adaptation responses, existing strategies, policies and initiatives need to be considered. Some actions defined as climate change adaptation are already occurring under a different name and it may be possible to modify existing programmes to provide a mechanism for delivering adaptation. An example of this is the planned incorporation of climate change adaptation into Natural England's Environmental Stewardship Scheme.

Natural England will be using this report to work with partners to refine the detail, seek consensus and implement the adaptation actions identified within the report.

Natural England is now working on the following:

- An implementation plan for the possible adaptation responses, which may include a demonstration project. Natural England will work in partnership with local stakeholders to ensure that this builds upon and dovetails with other initiatives:

- Providing ongoing input and support to the Shoreline Management Plan process and the Broads Authority led Broads Climate Change Adaptation Panel:

- Learning from the pilot process to assess likely climate change impacts and the possible adaptation strategies for other Character Areas both regionally and nationally:

The future of the Broads depends on the actions we all take today to reduce our greenhouse gas emissions. This, combined with decisions we make about managing our landscapes to adapt to unavoidable climate change, will determine whether we continue to have a high-quality landscape that is cherished and respected by all.

2. Background to The Broads Character Area

Box 2.1 Key Features of the Broads Character Area

- The Broads is one of Europe's finest and most important wetlands for biodiversity and is a significant habitat for a number of internationally important birds.
- The Broads has the largest expanse of species-rich fen in lowland Britain.
- Over 200 species of invertebrate have been recorded from dykes (drainage ditches).
- Iconic species in the Broads include the swallowtail butterfly, Norfolk hawker dragonfly, European crane and the bittern.
- Over half the Character Area forms the Broads nationally protected landscape of equivalence to a National Park. A further small area lies within the Norfolk Coast Area of Outstanding Natural Beauty (AONB).
- Landscape features include:
    - Broads and rivers and other shallow open water bodies;
    - Carr woodland;
    - Drained peat and peat clay mix;
    - Estuary;
    - Heathland;
    - Dune and coastal levels;
    - Estuarine marshland and grazing marsh;
    - Fen.
- Approximately 250 buildings within the Broads Character Area are listed. There are 74 surviving drainage mills and 13 ancient monuments.
- Happisburgh Cliffs SSSI and Bramerton Pits SSSI are nationally important for their geological interest.
- Soils in the Broads are mainly loamy and clayey soils of coastal flats with naturally high groundwater and fen peat soils.
- The Broads is one of the most extensive waterway systems in the United Kingdom, offering 190 kilometres of boating on lock-free tidal rivers and a significant fleet of private and hire boats.
- Specialist pike angling is particularly significant in the Broads and angling for coarse fish such as bream, eel, perch, pike, rudd and tench is very popular.
- Cycling is increasingly popular in the Broads and National Route 1 and Regional Route 30 pass through the area.
- The Broadland rivers are a significant source of water. There are also two major chalk aquifers in the Character Area.
- Three quarters of the open country is in agricultural use.
- Dunes, intertidal and wetland habitats in the Broads provides natural protection from coastal and fluvial flooding.

The Broads is a low-lying area on the eastern edge of East Anglia, between Norwich and the North Sea coast (see Figure 2.1). Its boundary roughly follows the edge of the floodplain of the rivers Yare, Bure and Waveney and their tributaries (see Figure 2.2). As well as the flat floodplain the Character Area also takes in the valley sides. 94% of the Character Area is open country and the remaining 6% is urban. Large parts of the floodplain are in grazing agriculture; however there are extensive areas of wet woodland and fen habitats in the middle valley reaches.

2.2 Significant natural environmental assets

In this section, the most significant natural environmental assets in the Broads Character Area are identified. Significant natural environmental assets are aspects of the natural environment that professionals working in the environmental sector and other knowledgeable people value most highly. These assets encompass biodiversity, landscape including historic and cultural landscape, recreation and access and ecosystem services.

It is important to identify the most highly valued existing environmental features in Character Area before assessing what the likely impacts of climate change will be on them. Current existing features define the Broads and form the basis of most adaptation responses (see Section 4).

2.2.1 Biodiversity

Internationally important features

The Broads is one of Europe's finest and most important wetlands for biodiversity and is a significant habitat for a number of internationally important birds. Virtually all the Site of Special Scientific Interest (SSSI) area (7,115 ha) is recognised as being of European importance, being classified Special Area of Conservation (SAC), Special Protection Area (SPA) and/or Ramsar Wetland of international importance.

The Broads SAC is considered to have a high diversity of habitats and species of European importance. It has been designated for alluvial forests with *Alnus glutinosa* and *Fraxinus excelsior*, calcareous fens with *Cladium mariscus* and species of the *Caricion davallianae*, alkaline fens, hard oligo-mesotrphic waters with benthic vegetation of the *Chara* species, M*olinia* meadows on calcareous, peaty or clayey-silt-laden soils, natural eutrophic lakes with *Magnopotamion* or *Hydrocharition*-type vegetation and transition mires and quaking bogs. Species of European importance recognised on this site include fen orchid (see picture 2.1), otter and Desmoulin's whorl snail.

Winterton-Horsey Dunes SAC supports a very diverse range of coastal dune communities, including embryonic shifting dunes, wet dune slacks supporting pools and mire vegetation, well established 'grey' dunes and acidified dune supporting heathland communities dominated by heather *Calluna vulgaris*. The pools are home to the rare natterjack toad *Bufo calamita.*

Figure 2.1 Location of The Broads Character Area

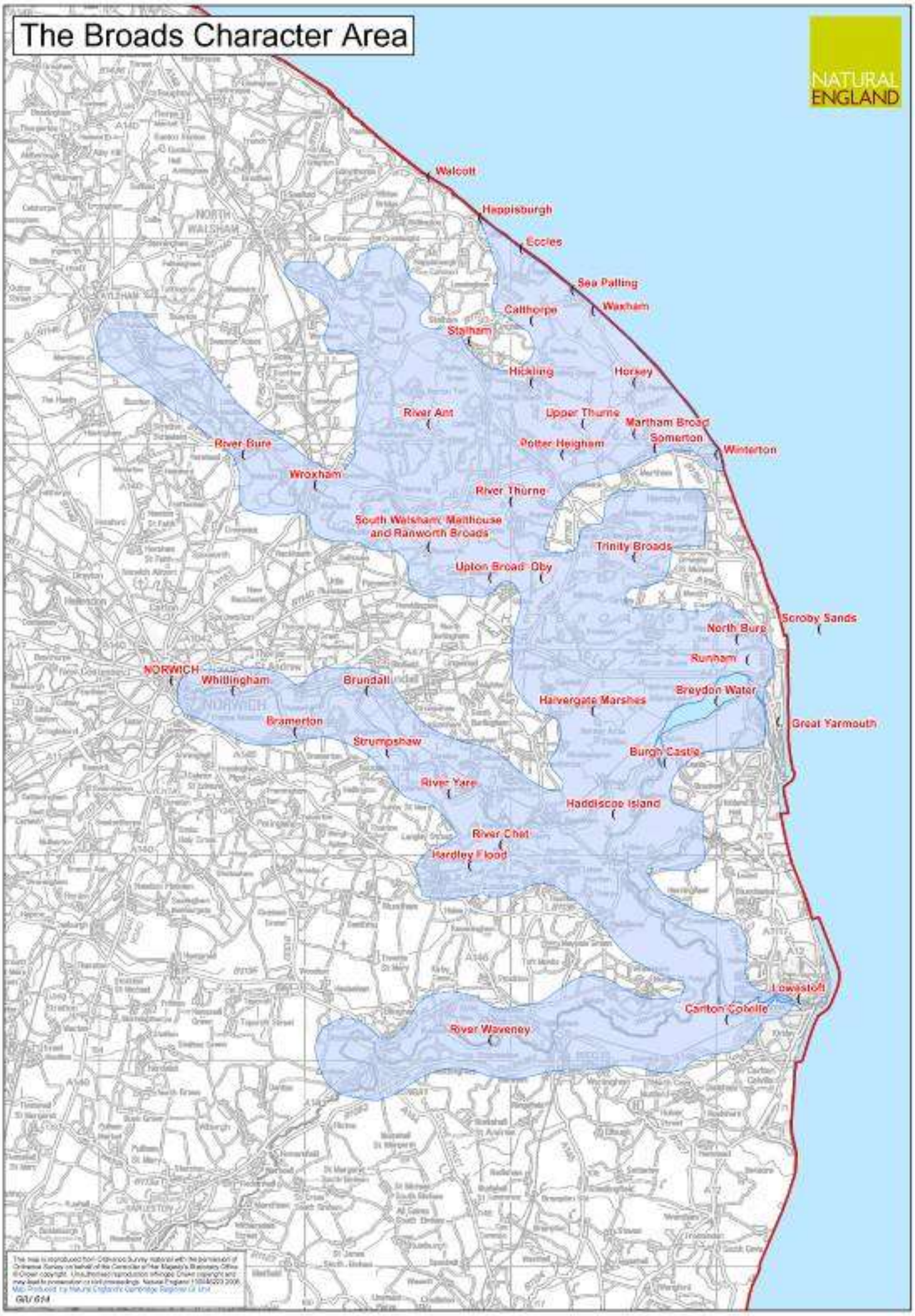


Figure 2.2 The Broads Character Area boundary and key locations referred to in the text

Picture 2.1 Fen Orchid

The Broadland SPA is important for bittern, Bewick's swan, whooper swan, marsh harrier, hen harrier and ruff. In addition, wigeon, gadwall and shoveler are regularly occurring migratory species (Carter and Tolhurst 1994).

Breydon Water SPA and Ramsar site supports internationally important numbers of waterfowl and waders. Important individual populations include black-tailed godwit, dunlin, lapwing, shoveler, wigeon, white-fronted goose, cormorant, golden plover, avocet, common tern and Bewick's swan (English Nature 2000).

Great Yarmouth North Denes SPA includes the beach and foredunes at Winterton-Horsey Dunes. This SPA supports a large breeding colony of little tern.

The Broadland Ramsar site is designated as it comprises many good and representative examples of wetland habitats characteristic of the biogeographical region (Carter and Tolhurst 1994b). It also supports an outstanding assemblage of rare plants and invertebrates and internationally important numbers of wintering wildfowl and wetland birds (Carter and Tolhurst, 1994b).

Figure 2.4 illustrates the present wetland interest of the Broads within a regional context, this data is from the 'A 50-year Vision for wetlands' (2008).

Nationally important features

There are 28 SSSIs that cover about 24% (7,166 ha) of the Broads Authority executive area. A further two SSSIs lie outside the Broads Authority executive area. Over a third of this SSSI area is designated National Nature Reserve (NNR).

The Broads has the largest expanse of species-rich fen in lowland Britain. About 17% of the floodplain area is undrained peatland. Of these 5,000 hectares approximately half is open fen with the remainder colonised by carr woodland and sallow scrub. The fens are home to over 250 species of plants. Coastal and estuarine grazing marsh accounts for 45% (13,500 ha) of the floodplain area.

Over 200 species of invertebrate have been recorded from dykes (drainage ditches), including 65 species of water beetle and many dragonflies and damselflies. The Upper Thurne is the richest site in Britain for stoneworts with 14 of the 21 species recorded in recent years. Table 2.1 lists some other nationally significant species found in the Broads Character Area.

Key Biodiversity Action Plan (BAP) species include water vole, otter, bittern, natterjack toad, shining ram's-horn snail, Desmoulin's whorl snail and holly-leaved naiad.

Table 2.1 Some other nationally important species found in the Broads

Species	% UK population
Crested buckler-fern	>95%
Fen orchid	50%
Holly-leaved naiad	100%
European crane	>95%
Bean goose	60%
Swallowtail butterfly	100%
Norfolk hawker dragonfly	95%
Dotted footman moth	100%

Locally important features

There are three Local Nature Reserves in the Character Area. There are also a number of iconic species which the Broads is known for. These may not be the most important species in terms of conservation interest (although they often are) but those which are popularly considered as representative of the area. Iconic species in the Broads include the swallowtail butterfly, Norfolk hawker dragonfly, European crane and the bittern.

2.2.2 Landscape and geodiversity

Over half the Character Area forms the Broads nationally protected landscape of equivalence to a National Park. A further small area lies within the Norfolk Coast Area of Outstanding Natural Beauty (AONB). The Broads is noted for its wilderness qualities.

There are a number of landscape types within the Broads Character Area, the most highly valued are described below:

The broads, rivers and other shallow open water bodies usually located within areas of peat fen. This landscape comprises of two sub-types: open broads, which are primarily a feature of the Upper Thurne area and tend to be embanked and fringed by reed (see picture 2.2), and the remainder, the enclosed broads which are bounded by encroaching carr woodland and floodplain fen.

Carr woodland usually comprising alders and willows on peaty soils. Carr woodland is found in wilderness areas that support a vast range of species.

Drained peat and peat clay mix areas are located in the upper valleys, smaller tributaries and on the upland margin of some areas of estuarine marshland. These areas are represented by a small scale pattern which has established through drainage and grazing use.

Estuary is characterised by intertidal muds, open (salt) water, saltmarsh, distinct accompanying vegetation types and a high importance for birdlife.

Heathland is found on sandy soils and includes distinctive vegetation types e.g. bracken, gorse and birch. It is usually in areas of dry common. These areas are located in a fragmentary way around much of the floodplain and adjacent to the coast.

Dune and coastal levels are characterised by dunes, raw sand, accompanying vegetation types and wildlife and the presence of the sea. Soft sediment cliffs are also found in the Character Area.

Estuarine marshland and grazing marsh occupies the extent of the former Romano-British estuary and is low lying land at or below sea level. It is divided into drainage levels, and each possesses a network of drainage ditches (known locally as dykes), with derelict drainage windmills and/or later pumping equipment positioned in association with embanked rivers or water courses (see picture 2.3). The marshland comprises tussocky grass on silty clay soils, in traditional grazing use. Marsh gates and side wing fences mark crossing points between individual marshes. These marsh levels are often fringed by carr woodland at the boundary with the 'upland'. Some areas have been degraded through management for arable cropping. The grazing marsh landscape type can be sub-divided into anciently enclosed with a sinuous drainage dyke pattern that has escaped improvement and the more recent rectilinear enclosed type. This landscape unit can also be classified into three landscape sub types dependant upon the degree of agricultural improvement: that which has escaped improvement; that which has been improved to grassland and that which has been improved to arable.

Photo credit (Mike Page)

Picture 2.2 Aerial view across the Upper Thurne basin showing Hickling Broad, fen, estuarine grazing marsh and woodland.

Photo credit (Mike Page)

Picture 2.3 Estuary, estuarine marshland and grazing marsh in the Broads

Fen is characterised by peat soils, containing watercourses, occupying marginally higher ground than the estuarine marshland (see Figure 2.4). It is often former wet common or poor allotment land. Relict medieval dole pattern of subdivision /drainage are retained in some areas. Others, usually 19th century attempts at drainage are sometimes shown by rectilinear dyke networks and some drainage mill remains, frequently abandoned.

Picture 2.4 Fen habitat in the Broads

This landscape type is often closely associated with broads, former broads and decoy sites, reed and sedge beds, fen meadows and scrub and carr woodland. Management regimes (or lack of) have a very significant impact on the appearance of fen areas. A large proportion has succeeded to scrub and carr woodland, although the Upper Thurne area where the influence of saline water is greater and the soils are more mixed is notable for its expanse of open fen.

There are a number of important cultural and historical landscape features within the Broads Character Area. Approximately 250 buildings within the Broads are listed.

There are 74 surviving drainage mills and 13 ancient monuments. Iconic buildings of the Broads include many of the drainage mills such as Berney and Thurne, the eel set on Candle dyke and the new sailing base at Whitlingham Broad. The Upper Thurne basin includes a very significant historical environment with three Grade I buildings, seven Grade II*, and many Grade IIs. These include the Grade I Waxham Hall of 1570, with its Grade II* gatehouse ands wall; the spectacular Grade I barn and the Grade II Norman church. The Broads also supports a number of traditional industries including reed and sedge cutting, thatching and eel fishing.

The Character Area possesses significant geodiversity assets. Happisburgh Cliffs SSSI and Bramerton Pits SSSI are designated for their nationally important geological interest. The Happisburgh Cliffs SSSI is designated for its cliff exposures which uniquely show three glacial deposits, the Cromer Tills (of Anglian age) with intercalated waterlain sediments and the underlying Cromer Forest-bed Formation. It is an important site for dating the Pleistocene succession of East Anglia with a range of sediments from marine to freshwater and glacial, spanning five stages, from the pre-Pastonian to the Anglian (Natural England 2007a). Bramerton Pits SSSI is also designated for its geological interest. Bramerton Common Pit has been regarded as the type section for the Norwich Crag of Lower Pleistocene age since the last century. While the nearby Blake's Pit has recently been designated the type site for the Bramertonian temperate stage. Studies of pollen, foraminifera and mollusca from Blake's Pit have demonstrated change from temperate to cold climatic conditions. It is a key locality of national importance to Pleistocene studies (Natural England 2007b).

Soils in the Broads Character Area are mainly loamy and clayey soils of coastal flats with naturally high groundwater and fen peat soils.

2.2.3 Access and recreation

The Broads is one of the most extensive waterway systems in the United Kingdom, offering 190 kilometres of boating on lock-free tidal rivers with a significant fleet of private and hire boats. There are 1,974 hectares of water space (6.5% of the floodplain area) and 63 permanently open water bodies. There are approximately 13,000 boats licensed to use the Broads. Boating infrastructure in the Broads also includes moorings, staithes and boat yards. Navigation and the maintenance of navigation in the Broads is managed by the Broads Authority.

Angling is an important recreational activity in the Broads**.** Specialist pike angling is particularly significant in the Broads and angling for coarse fish such as bream, eel, perch, pike, rudd and tench is very popular.

Under the Countryside and Rights of Way Act 2000 (CROW 2000), approximately 150 hectares of the Broads Authority executive (comprising 18 areas) has been designated as Access Land including 15 areas of Registered Common Land, and 3 areas of heath that are designated as open country within the definitions of the Act. There are a number of public rights of way in the Character Area including footpaths, bridleways and byways**.** Cycling is increasingly popular in the Broads and National Route 1 and Regional Route 30 pass through the area.

The value of tourism in the Broads in 1998 was about £146 million, of which 82% was generated by staying visitors and 18% by day visitors (Broads Plan 2004). In terms of staying visitors, there were one million trips to the Broads and a further 1.3 million trips made by day visitors. The majority of visitors to the Broads arrive by car. There are a number of towns which act as gateways to the Broads including Norwich, Great Yarmouth and Lowestoft. Norwich is a major rail terminal and the lines to Great Yarmouth, Lowestoft and the North Norfolk coast all run through the Character Area.

2.2.4 Ecosystem services

Human beings benefit from processes or structures within ecosystems that give rise to a range of goods and services called 'ecosystem services' (POST 2006). The Millennium Ecosystem Assessment grouped ecosystem services into four broad categories (UNEP 2006):

- Supporting services - such as nutrient cycling, oxygen production and soil formation. These underpin the provision of the other 'service' categories.
- Provisioning services - such as food, fibre, fuel and water.
- Regulating services - such as climate regulation, water purification and flood protection.
- Cultural services - such as education, recreation, and aesthetic value.

The Broads soils are mainly classified as loamy and clayey soils of coastal flats with naturally high groundwater and fen peat soils. Some soils in the Character Area are very fertile and there are parts of the area classified as Grade 1 or 2 agricultural land. The majority of the Character Area is Grade 3 agricultural land.

Three quarters of the open country is in agricultural use (or 70% of the whole Character Area). The majority of agriculture in the Character Area is mixed farming. Coastal and floodplain grazing marsh supports traditional grazing livestock and arable crops such as sugar beet, potatoes, winter barley, spring barley, vining peas, wheat, forage maize and lettuce can be grown.

The Broadland rivers are a significant source of water. Anglian Water abstracts water from the valleys of the rivers Yare, Waveney, Bure and Ant for potable supply. While Essex and Suffolk Water abstract from the Bure, Waveney and the Trinity Broads. In addition, water is also abstracted by a number of smaller abstractors for industrial and agricultural use**.** There are also two major aquifers in the Character Area, the Chalk and the Crag. The largest is the Chalk, used primarily for public water supply and spray irrigation.

The Broads is an attractive area for tourists (see Section 2.2.3). Many of the recreation and tourism assets also have value as an educational resource. There are a number of field study and visitor centres in the Broads.

Intertidal and wetland habitats in the Broads provides natural protection from coastal and fluvial flooding. Wetland habitats also have a role to play in moderating water quality.

The natural environment provides an important climate regulation function. Carbon is stored in soils, particularly peat soils, and biomass. There are significant areas of fen peat soils in the Broads, generally found along the margins of the floodplain and in the middle and upper river reaches.

2.2.5 All assets

An initial list of the most significant natural environmental assets has been compiled (see Table 2.2). Figures 2.3 to 2.6 illustrate the location of many of these assets within the Character Area.

Table 2.2 Significant natural environmental assets in the Broads Character Area.

Type of asset	Assets
Biodiversity	Wet carr woodland Reedbed and reedbed birds (including bittern and marsh harriers) Fens – floodplain and valley fens Purple moor- grass and rush pastures Broads and rivers Coastal and floodplain grazing marsh and breeding and wintering birds (including avocets, ruff and Bewick's swan) Ditch systems and ponds Lowland dry acid grassland and species rich grassland Lowland heath and heathland birds Saltmarsh and estuaries and estuarine birds Sand dunes and beach nesting birds Maritime cliff and slope
Access and recreation	Rights of way network – footpaths, bridleways, byways and cycle tracks Open water bodies and rivers Navigable waterways Boating infrastructure – moorings, staithes, boatyards Settlements and settlement 'gateways' Historic buildings Nature reserves and visitor facilities Sandy beaches and sand dunes
Landscape and geodiversity	Broads, rivers and other shallow open water bodies Carr woodland Drained peat areas Estuarine marshland and grazing marsh Fen Estuary Heathland Dunes and coastal levels Historic environment – buildings, field patterns and archaeology Geology Soils
Ecosystem services	Water resources and water quality Provision of food and fibre (farming, forestry and fisheries) Recreation and tourism Education Soils and geology Flood protection Climate regulation

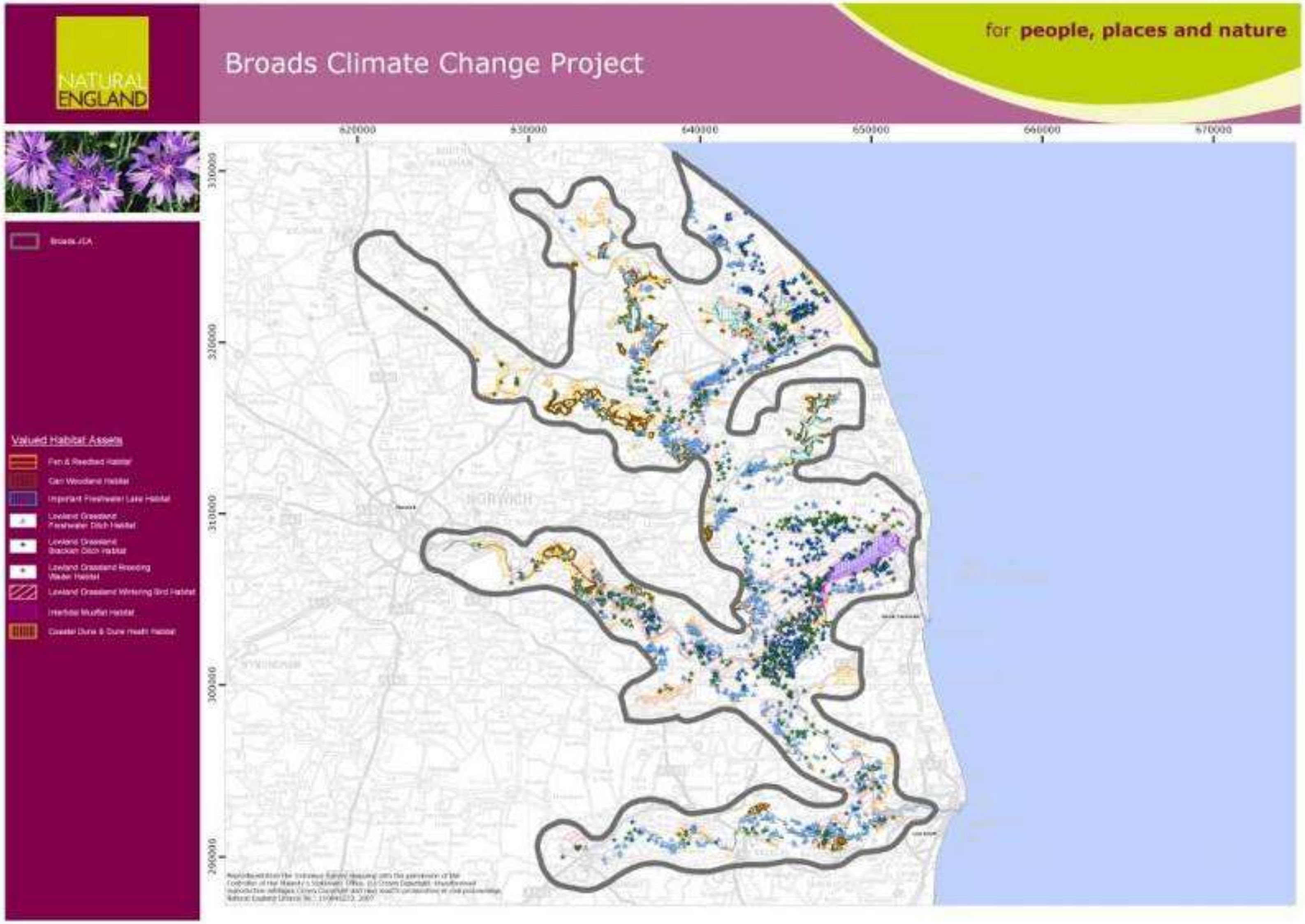


Figure 2.3 Significant biodiversity assets in the Broads Character Area

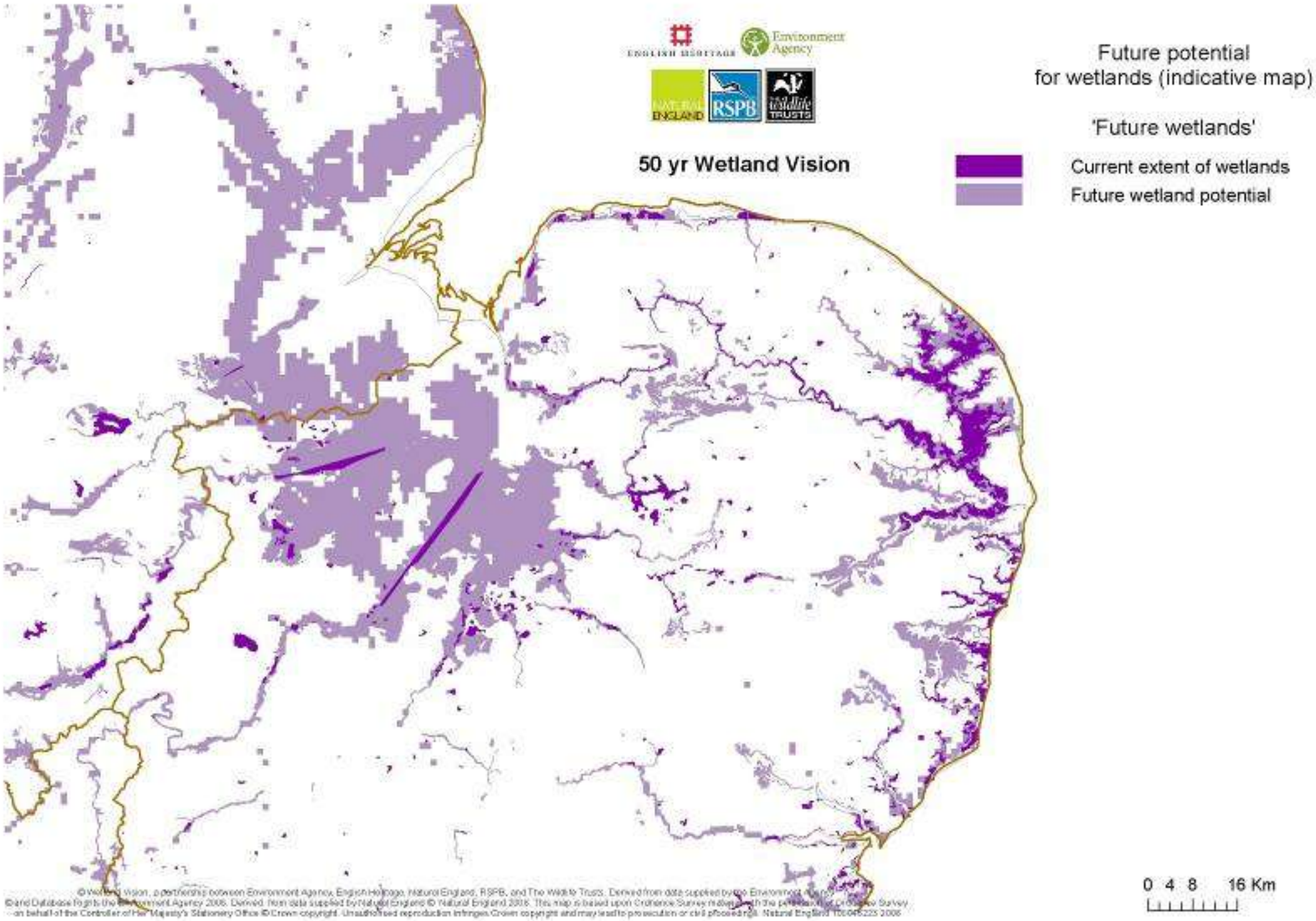
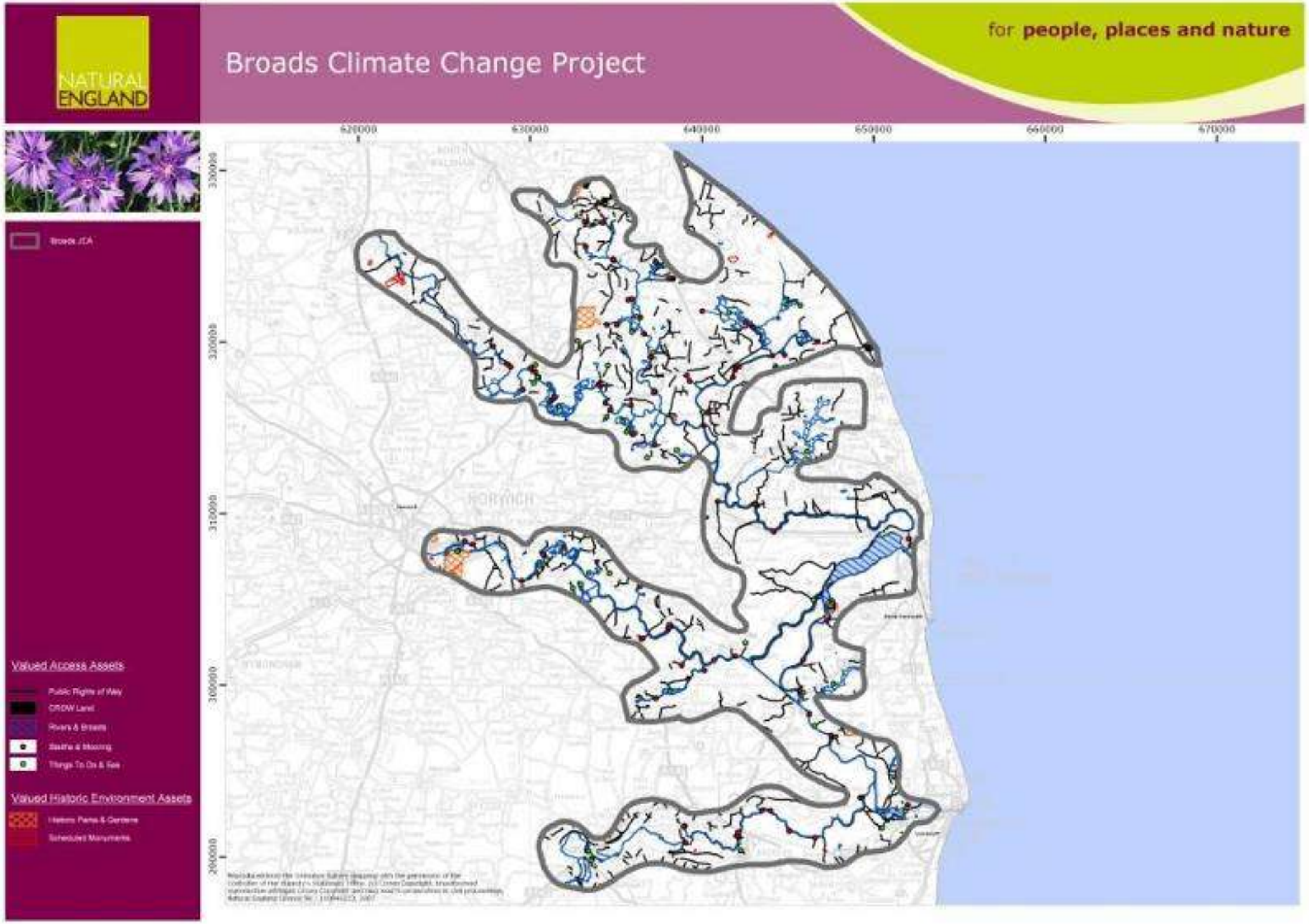


Figure 2.4 Wetland interest in the Broads and the wider East of England Region



Figure

2.5 Significant access and recreation assets in the Broads Character Area

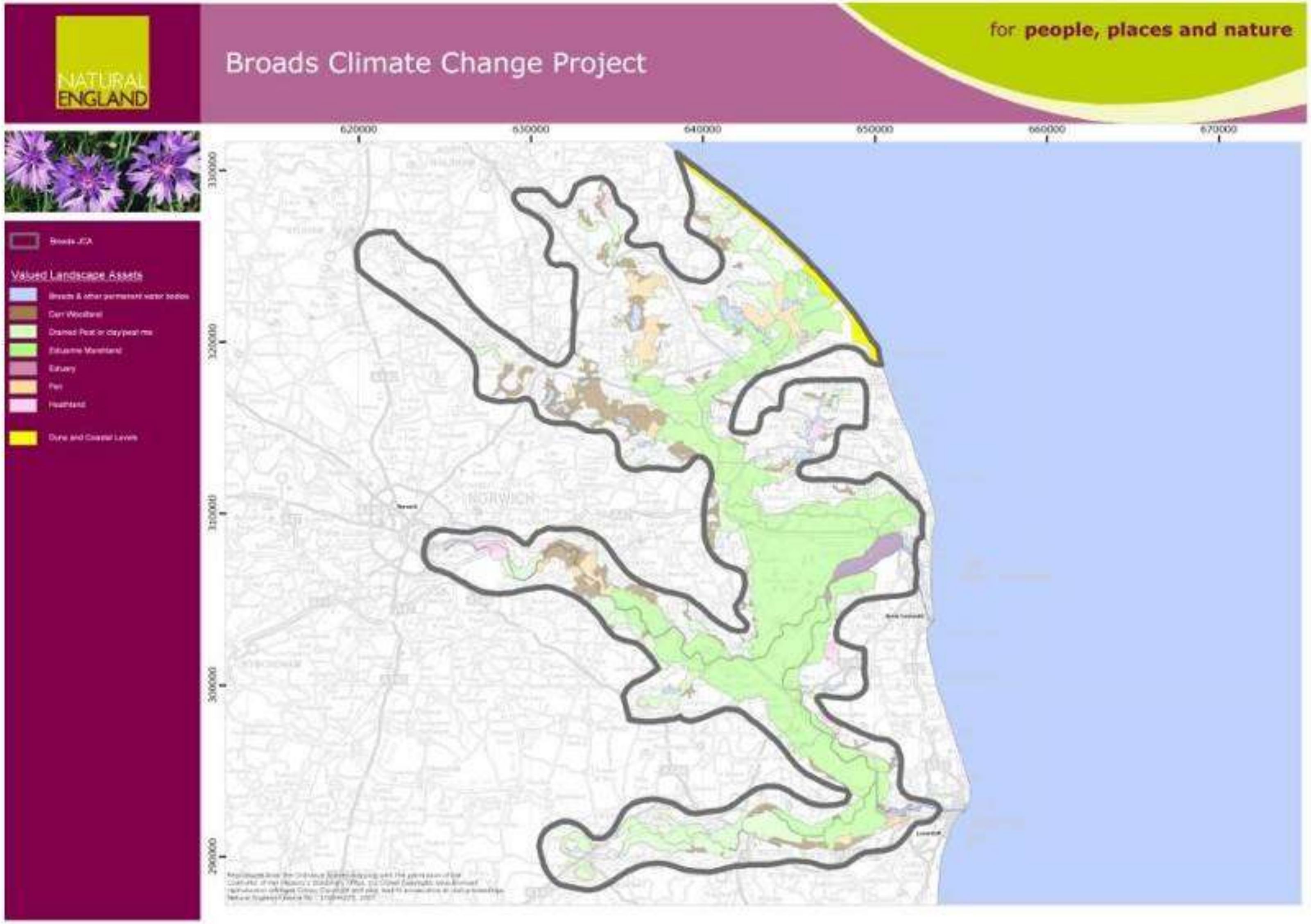


Figure 2.6 Significant landscape assets of the Broads Character Area

3. Impacts

Box 3.1 Key impacts of climate change on the Broads (assuming no adaptation)

- Sea level rise threatens to reduce the existing area of coastal habitats and modify the floodplain habitats in the Broads Character Area.
- Existing sea defences will become increasingly difficult to maintain, as beach profiles steepen and lower with an advancing high tide line.
- The frequency, penetration and duration of saline events will increase, possibly reducing the capacity of natural systems to recover.
- In addition to the threat of coastal flooding, climate change will increase the risk of fluvial flooding within the Broads.
- Many wetland habitats could be damaged by an increase in flooding.
- The Broads possesses a range of wetland habitats, all of which could be detrimentally affected by a decrease in summer rainfall.
- The ability of species and habitats to recover from repeated seasonal drought and flood events may be compromised.
- Species in the Broads may find themselves unable to move in response to climate change as the area lacks topographic variation and the floodplain is fragmented into many isolated flood compartments.
- Climate change may increase the number of non-native and invasive species.
- Changes in temperature will have phenological effects which are also likely to affect species and habitat composition.
- Increasing water temperatures reduce the solubility of oxygen resulting in a decrease in dissolved oxygen content of water.
- An increase in winter rainfall and annual temperature may increase the rate of erosion throughout the catchment, particularly in the headwaters, this could compromise water quality.
- Changes in temperature and rainfall may increase the incidence of pests and diseases.
- Air quality can be impacted by climate change and there may be consequent impacts on biodiversity.
- Climate change may have a greater impact on biodiversity through changes in agriculture than through direct bio-physical impacts.
- An increase in water temperature and saline penetration are likely to impact on angling.
- Potential for the re-introduction of vector borne diseases such as malaria to the Broads.

Box 3.1 continued

- Projected increase in summer temperature is likely to have an impact on water based recreation as water levels drop and water quality decreases.
- Rising temperatures are likely to increase the frequency of algal blooms in broads and rivers.
- The cost of waterways management may increase.
- An increase in visitor numbers may have negative impacts on wildlife and landscape and the opportunity must be carefully managed to prevent it becoming a threat.
- Some broad habitat types may persist (eg lowland acid grassland and lowland heathland) but the characteristic species that make up that habitat may be different, thus altering the appearance of the landscape.
- Bracken and scrub may grow faster under climate change and vegetation succession at the edge of water bodies may be more rapid.
- An increase in winter rainfall and annual average temperature may increase the rate of erosion at the coast.
- Habitat creation in response to climate change will impact on the landscape of the Broads.
- Reduced summer rainfall and more intense rainfall events in winter will impact on the water resources available for agriculture, recreation, potable water supply and habitats.
- An increase in the rate of physical processes could impact on the soils of the Character Area.
- Growth in population in the East of England could put further pressure on the Character Area as demand for housing, recreation, transport and other infrastructure would increase.
- Further development of wind power could impact on the landscape of the Broads and the coast.
- A change in species and habitat composition may affect the delivery of current conservation targets.

This section presents the latest information on predicted climate change and the likely impacts on the significant natural environmental assets in the Broads. This section presents what are likely impacts if no adaptation is undertaken.

3.1 Bioclimatic Data

3.1.1 Observed climate

In anticipation of the next set of UKCIP scenarios of climate change for the United Kingdom, due to be published during 2009, a report detailing observed climate for the United Kingdom for two 30 year periods 1961 – 1990 and 1971 – 2000 has been issued (Jenkins and others 2007). This report presents detailed observed data on the climate variables to be included in the UKCIP08 scenarios. The observed climate between 1961 – 2000 for the Broads geographical area can be seen in Table 3.1.

Between 1961 and 2000 some warming has been observed in the Broads. Warming is particularly marked in the summer and winter records with an annual average increase of 0.3 to 0.4°C. This is consistent with the UKCIP02 projections which forecast warmer summers and winters. The observed precipitation record shows less variability between the two thirty year periods.

Table 3.1 Observed climate of The Broads area

Climate variable		Observed climate 1961 - 1990	Observed climate 1971 - 2000	Change 1961-1990 to 1971-2000
Temperature	Annual mean	8 - 10°C	8 - 10°C	0.3 – 0.4°C
	Spring mean	8 - 10°C	8 - 10°C	0.3 – 0.4°C
	Summer mean	14 - 16°C	14 - 18°C	0.3 – 0.4°C
	Autumn mean	10 - 12°C	10 - 12°C	-0.1 to 0.2°C
	Winter mean	2 - 4°C	2 - 6°C	0.4 – 0.5°C
Precipitation	Annual mean	450 – 700mm	450 – 700mm	-2 to 2%
	Spring mean	100 – 180mm	100 – 180mm	-5 to 5%
	Summer mean	100 – 180mm	100 – 180mm	-5 to 5%
	Autumn mean	100 – 260mm	100 – 260mm	-5 to 10%
	Winter mean	100 – 180mm	100 – 180mm	-5 to 5%
Wind speed	Annual mean	No data	7 – 10 knots	NA
	Spring mean	No data	7 – 10 knots	NA
	Summer mean	No data	2 – 10 knots	NA
	Autumn mean	No data	7 – 10 knots	NA
	Winter mean	No data	7 – 14 knots	NA
Relative humidity	Annual mean	79 – 85%	76 – 85%	-0.9 - -0.3%
	Spring mean	76 – 82%	76 – 82%	-0.9 to -0.6%
	Summer mean	76 – 82%	73 – 82%	-1.5 to -0.3%
	Autumn mean	82 – 88%	79 – 85%	-0.9 to +0.2%
	Winter mean	85 – 88%	82 – 88%	-0.9 to -0.6%

Source Jenkins and others 2007

3.1.2 Climate change

The UKCIP02 scenarios forecast the impacts of climate change under a range of emissions scenarios for the UK (Hulme and others 2002). Scenarios for three different timeslices are presented, representing the average climate over 30 year periods centred on the 2020s, 2050s and 2080s. The climate changes projected to the 2020s are similar across all scenarios; this is because changes in the short term are dictated by Greenhouse Gas (GHG) emissions over recent decades. Climate changes beyond the next few decades depend on future emissions, but even the low emissions scenario represents an acceleration of climate change when compared to changes that have occurred in the 20th century The scenarios are based on a United Kingdom Met Office General Circulation Model (GCM), coupled to a Regional Climate Model (RCM) which allows impacts to be projected on a local to regional scale.

The bioclimatic data used in this project is taken from the HADRM3 model, a regional climate model with a 50 km^2 resolution, driven by different emissions scenarios; high and low emissions, based on the Intergovernmental Panel on Climate Change (IPCC) Special Report on Emissions Scenarios (SRES). The UKCIP02 high emissions scenario corresponds to the A1 scenario (see Appendix 2 for further explanation of socio-economic scenarios). Table 3.2 gives the bioclimatic data for the Broads Character Area. A visual summary of the major changes in rainfall and temperature expected is provided in Figure 3.1.

Changes in mean temperature or total rainfall as presented in Table 3.2 are not the only changes we can expect. It is likely that there will also be changes in extreme temperatures and rainfall events (eg an increase in heat waves and storms). It is important to note changes in extremes as they are likely to have the greatest impact on the natural environment. The frequency of such events and the pattern of different types of extreme event (eg drought followed by flooding) will have a compounding effect. The Broads are at risk from catastrophic events.

Table 3.2 Bioclimatic variables for The Broads Character Area

Climatic Variable	**Annual average value for The Broads Character Area**					
	2020s		**2050s**		**2080s**	
	High	**Low**	**High**	**Low**	**High**	**Low**
Change in absolute maximum temperature	1.42 ºC	1.19 ºC	3.39 ºC	2.13 ºC	5.87 ºC	3.02 ºC
Change in absolute minimum temperature	0.75 ºC	0.63 ºC	1.79 ºC	1.13 ºC	3.11 ºC	1.60 ºC
Change in minimum temperature expected over 20 years	1.05 ºC	0.89 ºC	2.51 ºC	1.58 ºC	4.38 ºC	2.24 ºC
Change in growing degree days >5ºC	344	287	832	520	1448	742
Change in mean temperature of the coldest month	No data	0.64 ºC	1.81 ºC	1.14 ºC	3.15 ºC	1.62 ºC
Change in mean temperature of the warmest month	No data	1.03 ºC	2.97 ºC	1.85 ºC	5.18 ºC	2.64 ºC
Change in total potential evapotranspiration	No data	24.5%	72.2%	44.4%	131.9%	64.1%
Percentage change in moisture availability	-40.8%	-34.4%	-100.2%	-62.0%	-180.3%	-89.0%
Change in total precipitation	-2.1%	-1.7%	-4.9%	-3.1%	-8.6%	-4.4%

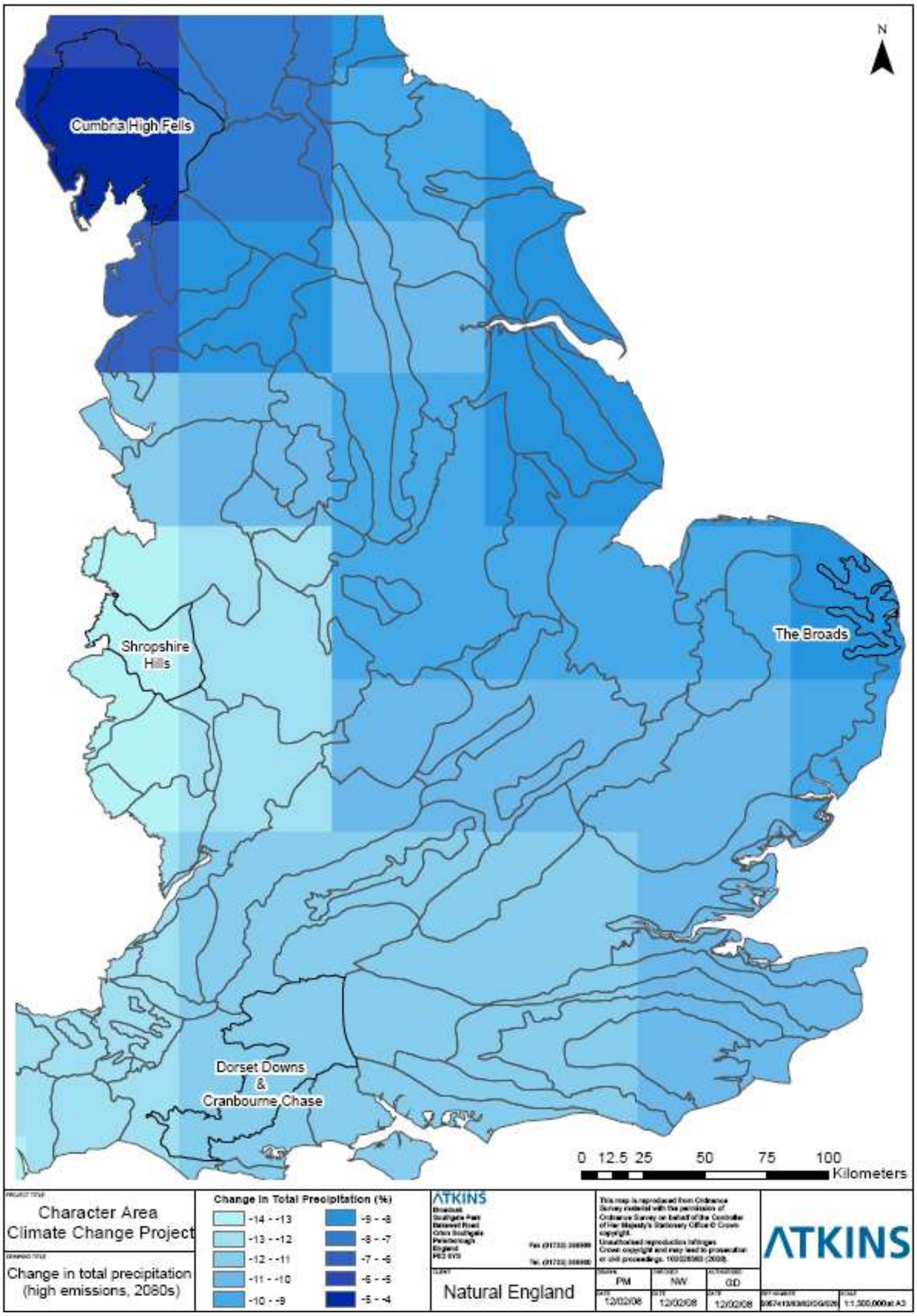


Figure 3.1 UKCIP02 scenarios for the Broads (2080s high emissions) a) total precipitation

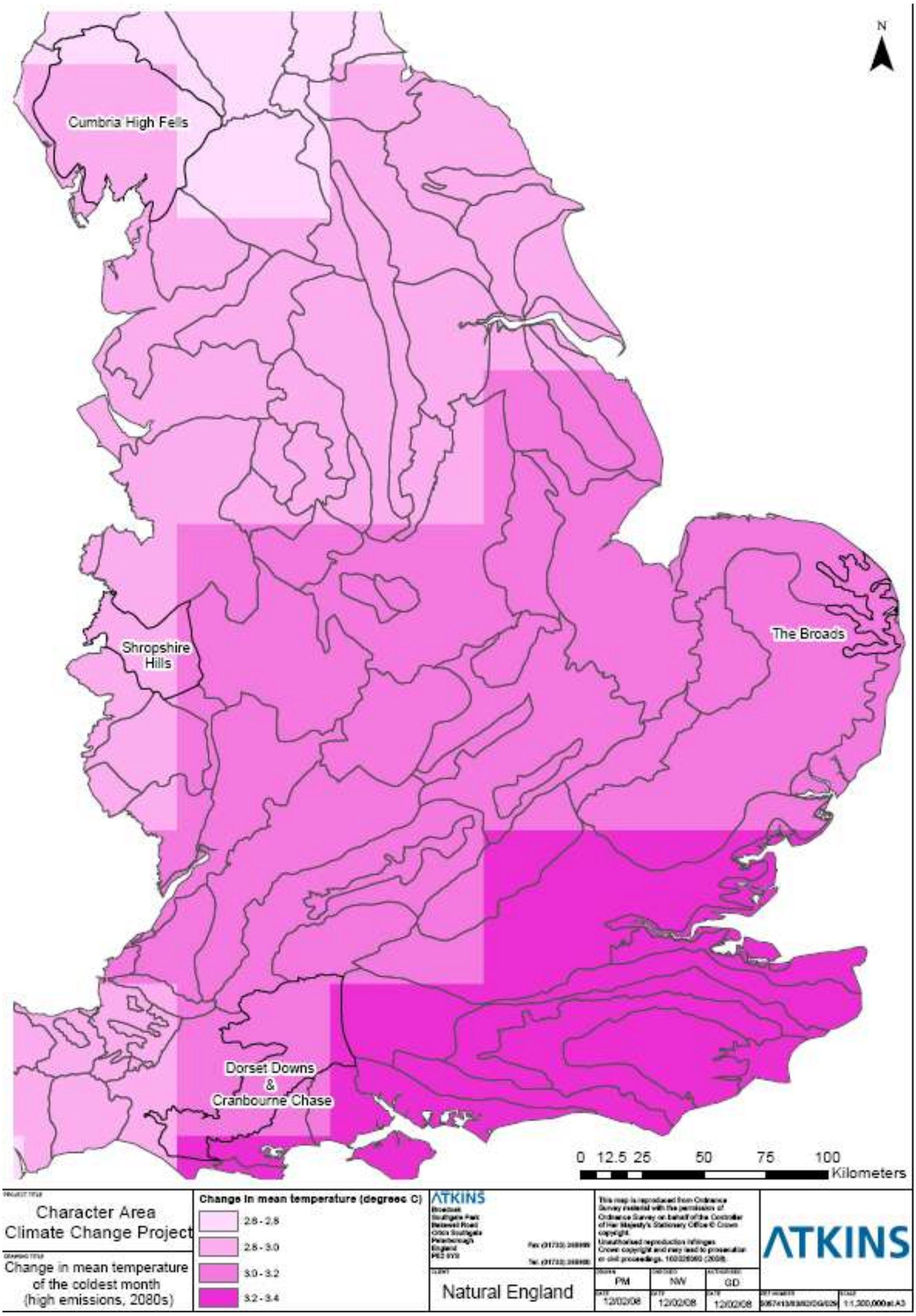


Figure 3.1 UKCIP02 scenarios for the Broads (2080s high emissions) b) change in mean temperature of the coldest month

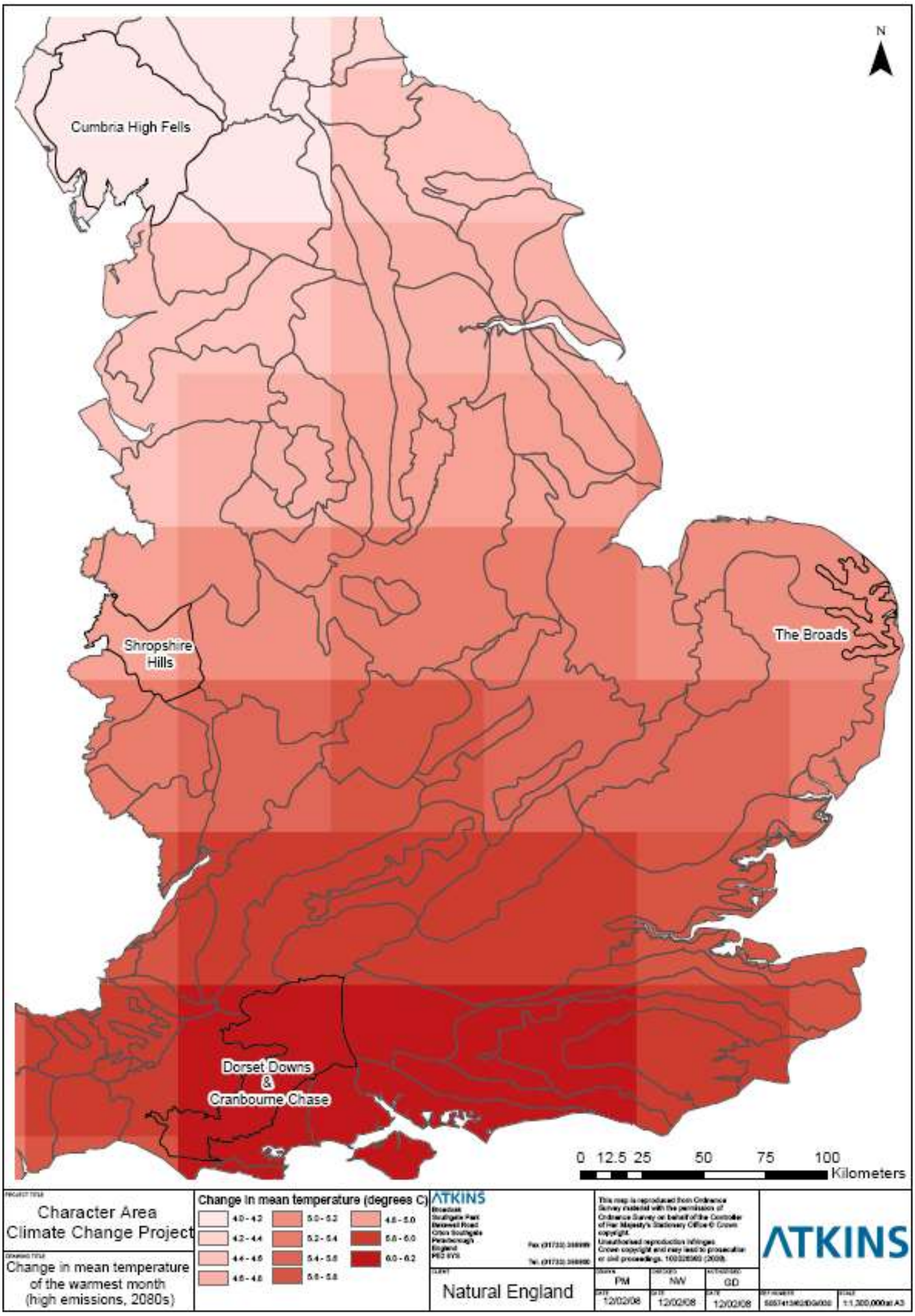


Figure 3.1 UKCIP02 scenarios for the Broads (2080s high emissions) c) change in temperature of the warmest month

Sea levels on the east coast of the United Kingdom are likely to rise as a result of climate change. Thermal expansion of the oceans due to warming combined with an increase in volume from melting ice caps and glaciers will increase sea level (eustasy). In addition, the south and east of England are sinking relative to the sea level as a result of ice unloading at the end of the last ice age (isostasy).

Global mean sea level is expected to rise by between 9 and 69 cm by the 2080s (the range represents emissions uncertainty). Regional figures incorporating isostatic uplift suggest a relative mean sea level rise of between 8 and 77 cm by the 2080s (UKCIP 2007) (see Figure 3.2). Storm surge heights in the Wash are anticipated to increase up to 1.2 m (including net sea level rise). However, changes in storm surge heights are only predicted with low – medium confidence (UKCIP 2002).

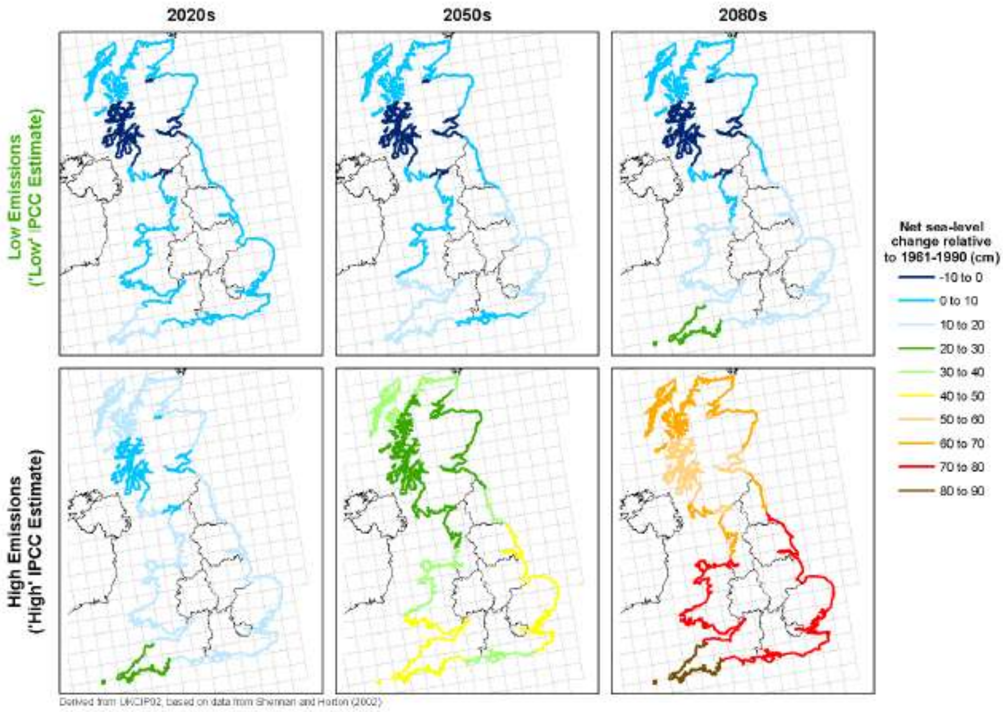


Figure 3.2 Sea level rise projections for the United Kingdom

Derived from UKCIP02 Climate Change Scenarios (funded by DEFRA, produced by Tyndall and Hadley Centres for UKCIP), based on Shennan and Horton (2002)

3.2 Types of impacts

Climate change will not be the only pressure on natural environments in the future. Other impacts will be felt through socio-economic change. The Broads is influenced by agriculture and changes in agricultural practices are likely to have a significant impact on its species, habitats and landscapes. Agriculture on the floodplain in turn is dependant upon continued investment in flood management and land drainage. Changes in agriculture could be driven by climate change, such as crop switching to more drought tolerant plants, or conversion of grazing land to arable. These would be classified as indirect impacts of climate change on the Character Area. However, changes in agriculture may occur regardless of climate eg fluctuations in crop prices or shifts in consumer demand for certain products. Such changes would be classified as socio-economic impacts. These changes, whether climate induced or not, would significantly impact on the environment of the Broads. In reality direct, in-direct and socio-economic impacts are closely related. This project focuses mainly on the direct biophysical impacts of climate change on the significant natural environmental assets. Where significant indirect impacts have been identified (such as those related to agricultural change in the face of climate change) these have been documented.

The interaction of climate change and socio-economic pressures adds another source of uncertainty to predictions of future impacts. The future will be different and we cannot predict what it will be like, although climate change and socio-economic scenarios can be used to help plan ahead (see Appendix 2). The impacts of climate change will be mediated by the socio-economic setting that prevails at the time; changes in attitudes, values and behaviour towards the natural environment and conservation will alter the nature of the impacts.

Whilst it is important to bear in mind that the future will be different, in order to identify impacts in this project, an assumption has been made that the socio-economic scenario that prevails in future will be broadly similar to that which we currently experience. As explained above this cannot be certain. In identifying climate change impacts, only one emissions scenario (high) for the 2080s has been used to indicate a direction of travel. This project has not adopted a formal scenario based approach, nor does it provide an integrated assessment of climate change and socio-economic scenarios as this is very complex.

3.3 Impacts on significant natural environmental assets in the Broads

The broad climate changes projected in the UKCIP02 scenarios and the bioclimatic data given in Table 3.2, along with published research, was used to identify the likely impacts on the significant natural environmental assets in the Character Area. Whilst there is some uncertainty over the nature of climate change, and its detailed impacts, this report brings together the best available information on impacts based on the latest science and expert judgement. From this understanding, an initial set of responses has been defined (see Section 4).

Table A3.1 in Appendix 3 identifies the climatic changes pertinent to the significant environmental assets and the likely impacts, which are discussed further below. Table A3.1 describes the impacts of climate change on the Broads assuming no adaptation action is taken. The situation envisaged is therefore the ‘do nothing’ scenario for the Broads. Whilst it is unlikely that this scenario will be taken, it is useful to identify the impacts of climate change in order that the degree of adaptation required can be gauged. In identifying the impacts associated with this scenario, an assumption has been made that climate change will be gradual and that there will not be sudden catastrophic events which materially alter the landscape of the Broads in a permanent or semi-permanent manner. However, given the nature of low frequency extreme events this cannot be guaranteed.

3.3.1 Impacts on biodiversity assets

Direct impacts

The low elevation of the land within the Broads makes it vulnerable to sea level rise, reducing the area available for habitats and species. Sea level rise threatens to reduce the existing area of coastal habitats and modify the floodplain habitats in the Broads, through ‘coastal squeeze’ whereby the area of habitat is prevented from moving landward in response to sea level rise by floodplain and coastal defences. Saltmarshes and estuaries, beaches and sand dunes and maritime cliffs and slopes could be affected by 'coastal squeeze'. Lowering of the beach will reduce the habitat available to the internationally important breeding population of little tern on Winterton beach. Loss of saltmarsh within Breydon Water and along the lowest river reaches is of particular concern as it forms the base of estuarine food webs, supporting many estuarine birds such as redshank and curlew. It also provides an ecosystem service; protecting the confining earth flood embankments from erosion by wave energy.

A wider impact of sea level rise is that water levels throughout parts of the Broads will increase. Areas connected to the rivers and not isolated by earth embankments will become progressively wetter. This could have a major impact on species and habitat distribution, with fen changed to species-poor reedbed and the scrub and carr woodland drowned. The degree of impact will be dependant upon the topography and location within the floodplain.

However, sea level rise will not only affect coastal and estuarine habitats. The Broads is one of the most important freshwater wetland systems in the United Kingdom. Climate change will threaten these habitats through saline intrusion and incursion. Saline intrusion linked to a storm surge are experienced several times every winter. In the past two years these have been particularly severe, forcing a wedge of sea water into the usually freshwater middle reaches of the rivers. This also results in a zone within the floodplain system that fluctuates between fresh and saline conditions.

In addition to saline intrusion and incursion, the Broads are also vulnerable to catastrophic events that could result in overtopping and breach of defences.

Table A3.1 identifies a number of habitats at risk of saline incursion and intrusion including the broads themselves, reedbeds and fens and carr woodlands. Increased saline incursion into the Broadland rivers will result in the conversion of brackish reedbed along the lower river reaches to upper saltmarsh habitat. However this might be a temporary state as increasing water levels may flood this out. Grazing marsh ditches are an important habitat in the Broads, some of which currently exhibit a range of fresh to saline water conditions with a brackish transition zone closest to the river. As the rate of sea level rise increases, land levels continue to sink and the rate of settlement of embankments built on poor ground increases it may become increasingly difficult to sustain the standards of flood management. Even with a constant standard of flood management and drainage regime into the future, the brackish transition zone is likely to move further upstream and penetrate further into the ditch systems as a result of saline intrusion. This tend has already been observed in Broadland ditch systems since the early 1970s, including those of the Upper Thurne (Doarks 1990). This impact is likely to be exacerbated with reduced summer freshwater flows into these ditch systems. Under high tides and surge conditions the saline wedge will penetrate further up the Broads river systems. It is likely that flips between saline, brackish and freshwater states will occur in some of the broads connected to the river system, broads such as South Walsham Broad, Malthouse Broad and Ranworth Broad. Increasing salt surges also impact the freshwater fishery of the Broadland rivers. The key impact of climate change is that the frequency, penetration and duration of saline events will increase, possibly reducing the capacity of natural systems to recover.

It is important to recognise that sea water enters the Broads in three ways: through the Haven at Great Yarmouth, under the dunes along the 14 kilometre coastal frontage between Eccles to Winterton into the Upper Thurne basin, and to a much lesser extent from the overtopping of sea defences at Walcott into the headwaters of the river Ant. All these saline inputs into the Broads are likely to increase over time. Recent survey undertaken by the Broads Internal Drainage Board have demonstrated how very significant the sea water ingress is under the coastal dune frontage into the Upper Thurne basin. This has shown that much of the ingress is from drains located adjacent to the coast, and that this water is then pumped by land drainage primarily into Horsey Mere (Harding and Smith. 2002). A further study has also been undertaken to investigate the feasibility of solutions to address both salinity and ochre problems of this area (ELP. 2005). While other research has shown that the broads of the Upper Thurne have become significantly more saline during the 20th century, much of this change is likely due to the deep drainage and pumping that has and continues to occur. In some places pure sea water enters the coastal drains as the sea water table has been punctured. This impact is likely to increase over time impacting biodiversity, landscape and pike and coarse angling.

However, in addition to coastal flooding, climate change will increase the risk of fluvial flooding within the Broads. A projected increase in winter rainfall of 30-40% under the 2080s high emissions scenario (Hulme and others 2002) and an increasing frequency of high intensity rainfall events will result in increased water levels in Broadland rivers and is likely to lead to an increase in flood risk. It is likely that the frequency of flood events will increase later in winter than at present. Many wetland habitats could be damaged by an increase in flooding. The impact of fluvial flooding should not be underestimated. Indeed it must be recognised that the major floodplain fen habitats of the rivers Yare, Ant and Bure lie in situations where they are impacted by both tidal and fluvial events. Over time with increasing sea level the Broads might become increasingly tide locked, exacerbating flooding impacts on undefended floodplain areas. There is already evidence that water levels have risen in the Yare valley. It is possible to lower such water levels by reconnecting parts of the embanked and drained floodplain to the river system. The return of such areas to naturally functioning wetland would reduce water levels within the river system, thus reducing damage to internationally important floodplain fen and people and built property situated adjacent to rivers and within the undefended floodplain area. While such an approach could be used to moderate water levels (tidal and fluvial) it would be less effective at combating increasing saline intrusion.

Prolonged inundation of purple moor-grass and rush pasture may cause a shift towards true fen or swamp communities. Fens situated on naturally functioning floodplains (un-drained) are also likely to be affected by increasing water levels as a consequence of higher intensity rainfall and its interaction with sea level rise. Inundation of floodplain fens is also likely to increase as the frequency and duration of flooding increases, bringing with it increased sediment and nutrient loading. Reedbeds and coastal and floodplain grazing marshes behind embankments face similar risks to true floodplain habitats. Breeding birds associated with reedbeds are increasingly vulnerable to flooding and ground nesting species could be lost. Flooding could also threaten the integrity of alluvial flood meadows as the component plants of this habitat are more vulnerable to increasing wetness than summer drought. High water levels during late winter are already affecting harvesting of commercial reedbeds, reducing the viability of this cultural activity and the beneficial management it delivers (R Starling personal comment).

In addition to winter flooding, wetland habitats will also be affected by summer drought. A projected decrease in summer rainfall of up to 60% under the 2080s high emissions scenario (Hulme and others 2002) may lead to more frequent droughts which would severely affect wet woodland and coastal and floodplain grazing marsh. Although these habitats may not be completely lost, their composition may change. The summer water level in reedbeds, fens and purple moor-grass and rush pastures is also likely to decline and these habitats may suffer seasonal drying out. This would lead to a reduction in associated species, particularly birds such as bittern and European cranes, and a loss of landscape character. Commercial reed and sedge harvests could be detrimentally affected, reducing this cultural activity and the landscape and biodiversity benefits it delivers. Ditches are used as stock proof barriers, insufficient water would make maintenance of grazing on the grazing marshes very difficult. Faced with drought conditions graziers are likely to introduce poorer quality and possibly slightly brackish river water into their ditches. Such practice, while meeting the needs of agriculture, damages the biodiversity of the grazing marsh ditches as evidenced on the River Bure (Doarks. 1990).

A further impact of climate change may be greater variation between seasons. Whilst habitats may be able to recover from individual flood or drought events, a seasonal cycle of flooding and drought is likely to put significant pressure on habitats. The ability of species and habitats to recover from repeated seasonal drought and flood events may be compromised.

Results from the Monarch study (Walmsley and others 2007) indicate that certain species will gain suitable climatic space in the North and West whilst losing it in the South. A projected increase in annual average temperature of 3.5 – 4.5°C in the Broads (Hulme and others 2002) is likely to cause species to move. Broadly speaking climate change will encourage species to move to higher ground and to north facing slopes. However, species in the Broads may find themselves unable to move in response to climate change as the area lacks topographic variation and the floodplain is fragmented into many isolated flood compartments. Compositional changes are likely in a number of the key habitats in the Broads including:

- Loss of freshwater flora and fauna either periodically or permanently from wetland habitats;
- Loss of boreal species from fens;
- Potential decline and loss of boreal montane and boreal temperate species from fen meadows;
- Loss of oceanic lowland acid grassland species and increase in Mediterranean species;
- Change to a sandier substrate in saltmarshes and estuaries affecting vegetation type, invertebrates and birds.

As some species are likely to lose climate space, others will gain it. It can be useful to look at neighbouring Character Areas to assess which species may move in. For example, Spanish catchfly *Silene otites* is currently found in Breckland but under warmer conditions it is expected to spread north and east, possibly into the heathland areas within the Broads Character Area. Not all the species gaining climate space are welcome; climate change may increase the number of non-native and invasive species. Aquatic exotic alien plants are already gaining a foothold in the Broads, species such as floating pennywort (see picture 3.1), parrot's feather and Australian swamp stonecrop.

Picture 3.1 Broadland grazing marsh ditch infested with the invasive alien, floating pennywort

Some aliens may bring both positive and negative impacts, species such a zebra mussel and Asian clam.

Other examples of species change in the Broads Character Area include:

- Increase in 'dryland' species in purple moor-grass and rush pasture habitat.
- Increase in annual species at the expense of perennials in lowland acid dry grassland habitat.
- Scrub invasion and woodland succession in wetland habitats isolated from changes in river water level.
- Growth of rhododendron which would eliminate valued dune, dune heath and heath habitats.

Changes in temperature will have phenological effects which are also likely to affect species and habitat composition. For example, it is predicted that temperature changes may cause certain lowland hay meadow species to flower/set seed earlier in season in the Broads. Phenological changes are already being observed in the United Kingdom; earlier arrival of birds and butterflies in the spring have been recorded (Sparks and others 2001) and tree leaf appearance in Surrey has been found to be ten days earlier in the 1990s than the 1980s (Sparks and others 2001). Changes in phenology are another cause of species and habitat compositional change as changes in the relative timing of events has knock on effects for other species. Phenological changes may affect bird species whose breeding cycles are adapted to those of their prey, usually invertebrates.

An increase in temperature may also impact on water bodies and freshwater species. Dissolved oxygen is important for fish and other aquatic life and is partly a function of water temperature. Increasing water temperatures reduce the solubility of oxygen resulting in a decrease in dissolved oxygen content of water. This may result in fish kills and loss of aquatic species.

An increase in winter rainfall and annual temperature may increase the rate of erosion throughout the catchment, particularly in the headwaters. This could compromise water quality, affecting a number of significant natural environmental assets. Deterioration of water quality and increased sedimentation will impact both biodiversity and water based recreational interests. Internal erosion within saltmarshes and the banks of the lower rivers are also likely to be affected by climate change with consequences for increased sediment transport.

Changes in temperature and rainfall may also increase the incidence of pests and diseases. Alder trees in the Broads are already suffering from the effects of the fungi Phytopthora; warming temperatures are likely to result in an increased spread of Phytophthora species in the United Kingdom. Trees stressed by drought are also more vulnerable to Phytopthora.

Air quality can be impacted by climate change and there may be consequent impacts on biodiversity. Concentrations of low level ozone are predicted to increase as temperatures warm. Ozone pollution can affect biodiversity; studies of ozone effects on grassland communities have reported changes in species composition (Morrissey and others 2007). Other habitats, such as wetlands and heaths are poorly studied although there is some evidence that bog habitat is sensitive to ozone (Morrissey and others 2007).

Indirect impacts

In addition to direct effects of climate change, the biodiversity of the Broads will be impacted by indirect impacts of climate change on other sectors that interact with biodiversity. The key sector in the Broads is agriculture; changes in agricultural practices as a result of climate change will have indirect impacts on biodiversity. Climate change may have a greater impact on biodiversity through changes in agriculture than through direct bio-physical impacts. For example, an increase in the area of cultivation as a response to longer growing seasons and the development of new crops may impact on the area and the quality of the landscape and the biodiversity of the grazing marsh network. Grazing changes will also be required in response to changing patterns of vegetation growth. It is likely that winter growth will increase as temperatures warm, which may require changes to grazing practices.

Agriculture also affects the permeability of the landscape, allowing migration of species along habitat networks. Creation and extension of biodiversity-friendly networks will be constrained by the presence of intensive agricultural land uses impermeable to species. These indirect impacts of climate change will be mediated by the prevailing socio-economic scenario in the future (see Appendix 2) and the state of agricultural economics is hard to predict. The future of agriculture in the Broads is also intrinsically linked to the policy and economics of flood risk management and land drainage.

3.3.2 Impacts on access and recreation assets

Direct impacts

Whilst the greatest impact on access and recreation assets may be due to an increase in visitor numbers (an indirect impact of climate change) there are a number of direct impacts of climate change on recreation assets.

An increase in water temperature and changes in saline penetration are likely to impact angling within the Broads. An increased water temperature and changes in saline penetration are likely to result in seasonal changes in fish movement, with fish spending more time in the upper river reaches. Such a change would potentially cause conflict between angling and boating in these congested reaches. It is likely that an increase in temperature will impact on fish spawning although knowledge of fish spawning sites is poor, making the impacts hard to predict. Changing water temperature is also likely to alter the fish species present. Carp and European catfish may increase under such conditions.

A projected increase in summer temperature of 4.5 – 5.0°C under the 2080s high emissions scenario (Hulme and others 2002) is likely to have negative effects on water based recreation as water levels drop and water quality decreases. An increase in temperature could increase the presence of midges and flies around the water bodies of the Broads. Wetland creation may increase the incidence of insects and pests as the shallow water conditions provide suitable breeding sites. This could reduce the attractiveness of the area to visitors.

Possibly more serious is the potential for the re-introduction of vector borne diseases such as malaria to the Broads. The Health Protection Agency (HPA) has mapped malaria suitability under recent climate and a range of future climate scenarios illustrating the number of months introduced mosquitoes could persist in the United Kingdom. Under all climate change scenarios, the risk of malaria transmission is predicted to increase in southern England, including the Broads (HPA 2008). Saltmarshes support a domestic species of malaria carrying mosquito which breeds in brackish water (HPA 2008). An increase in saltmarsh area in the Broads and the impact of saline intrusion may increase the availability of breeding sites for this species of mosquito.

Rising temperatures are also likely to increase the frequency of algal blooms in broads and rivers. As well as being unsightly, blue-green algae can have negative effects on human health. An increase in summer temperatures could also increase the prevalence of heat related illness; sun stroke, sun burn and heat exhaustion. Currently the winter months are regarded as the most dangerous for outdoor recreation but it is possible that the summer months could become the most significant in terms of weather related illness.

An increase in flood risk may impact on rights of way and visitor attractions, although as flood risk is likely to be exacerbated in later winter and early spring, the impact on the tourism industry may be limited. An increase in standing water on footpaths and other rights of way may lead to more rapid erosion. Flooding of footpaths situated on the floodplain could lead to a reduction in the length of footpath available unless they were raised using boardwalks, bridges and embankments. However, this is unsustainable and costly. Access along flood embankments will be impacted only by extreme events, however they are wholly dependant upon the continued maintenance of the embankments.

The cost of waterways management may increase as a result of climate change. An increase in the duration and frequency of flooding would negatively impact waterside facilities and infrastructure, sailing, boating and navigation. Generally higher water levels throughout the Broads will make it more difficult for craft to pass through the bridges on the system. The old bridge at Potter Heigham already limits the size of craft able to pass in and out of the Upper Thurne. In addition to flooding, an increase in sediment load may increase waterways management costs as more frequent dredging would be required. The impacts of climate change on navigation may affect boatyards in the Broads which may not remain viable.

Sea level rise and associated coastal erosion will also threaten recreation facilities at the coast, such as the Winterton beach café, car park and even the eventual losses of the beaches themselves.

Indirect impacts

The impacts of climate change on recreation assets in the Broads are mainly indirect, due to an assumed increase in visitor numbers as a response to an increase in temperature. Whilst this assumption may be valid under the current socio-economic scenario, this may not be the case under alternative scenarios where people have different attitudes towards the environment or where incomes are different. The assumption that visitor numbers would increase has been made in this report and in Table A3.1 in Appendix 3.

A rise in temperature and the consequent rise in visitor numbers can be seen as an opportunity or a threat for the area. Currently, the amount of winter tourism in the Broads is low; the impact of climate change may be to extend the tourist season as the autumn and spring months become popular. It is anticipated that the greatest increase in visitor numbers will be in the shoulder months.

In terms of recreation and enjoyment of the natural environment, climate change may present an opportunity. In the Broads there are likely to be particular opportunities for water based activities and waterside locations as people seek cooler, shadier places in the warmer months. However, an increase in visitor numbers may have negative impacts on wildlife and landscape and the opportunity must be carefully managed to prevent it becoming a threat. A number of potential negative impacts of an increase in visitor numbers can be identified including:

- Congestion at ‘honeypot’ sites or on popular rights of way leading to a reduction in visitor experience and wilderness quality, increase in litter, noise, pollution etc;
- Increased use of water bodies and navigable waterways causing congestion and increased erosion;
- Greater pressure on water resources and sewage treatment works;
- Increased demand for visitor infrastructure e.g. accommodation and resources;
- Congestion on transport infrastructure e.g. roads, car parks, trains;
- Increased disturbance to sensitive wildlife - the Broads are internationally important for their wintering bird populations; these are dependant upon maintenance of refuge areas;
- Trampling of sensitive wetland habitats;
- Indirect impacts e.g. footpath erosion, enhanced sedimentation of rivers.

3.3.3 Impacts on landscape and geodiversity assets

Direct impacts

Section 2.2.2 identifies the significant landscape assets present in the Broads Character Area. Changes in the elements and patterns that shape landscape character have an impact on the overall quality of the countryside (Countryside Quality Counts, undated). As Table 3.3 demonstrates, climate change will directly impact on the landscape of the Broads. Some broad habitat types may persist (e.g. lowland acid grassland and lowland heathland) but the characteristic species that make up that habitat may be different, thus altering the appearance of the landscape.

Some floodplain and coastal habitat types may be reduced in extent or lost entirely from the Character Area due to flooding and sea level rise. An increase in winter rainfall leading to flooding as well as sea level rise may increase the presence of water throughout the Broads and revert parts of the floodplain to a more natural wetland. Losses of sandy beaches and sand dunes can be expected at the coast if adaptation does not facilitate their roll-back or the current intervention in the form of beach feeding is not continued. Whilst further inland, losses of wet woodland, fen and coastal and floodplain grazing marsh is likely.

Open water bodies are likely to alter under climate change. Bracken and scrub may grow faster under climate change and vegetation succession at the edge of water bodies may be more rapid. This may be offset by increased water levels. Without management, within the drained parts of the floodplain it is likely that scrub will dominate the landscape more than it does at present. This would be detrimental to the wetland and grassland networks as well as geological sites although could be beneficial for the woodland network. This though in part is linked to the ability to maintain grazing and cutting regimes into the future. The impacts of climate change may act as ‘forward switches’ in shallow water bodies, shifting them towards turbid algal dominated lakes. This will have a negative impact on the landscape as they will be of lower aesthetic value than the clear water, plant dominated lakes that exist in places such as Martham Broads and Upton Broads.

Climate change will also impact on the historical environment. The effect of rising sea levels will cause coastal erosion and endanger historic maritime landscapes, structures, buildings and archaeology. Some of the historic features of the Broads landscape are windmills and pumps used to drain the marshes. These features are likely to be affected by subsidence caused by the drying out and cracking of soils during periods of drought or by an increase in the risk of flooding. The repeated cycle of wetting and drying will affect the foundations of historic buildings and may exceed their capacity to support the structure. An example of this is Strumpshaw drainage pump on the River Yare, here the pump house has subsided and the chimney acquired a significant list. Direct damage and damage to their setting can also occur through the engineering works required to maintain the earth embankments on which they sit. More frequent and severe flooding, may damage some historic buildings (and create difficulties in obtaining insurance, which may make others uneconomic to occupy and maintain). Changes in hydrology may put archaeological remains at risk. Increased frequency of extreme weather or a change in its geographical distribution could result in an increased risk of damage to both landscapes and buildings. Authentic planting schemes in historic parks may become untenable due to direct climate change and new pests and diseases. Climate change may also impact on the cultural landscape of the Broads. More information on ‘Climate Change and the Historic Environment’ can be found in the English Heritage Statement on this subject (2006).

An increase in winter rainfall and annual average temperature may increase the rate of erosion at the coast. Cliff erosion and an increase in frequency of landslides will reduce the amount of vegetated maritime cliff and slope habitat in the Character Area. An increase in erosion may lead to the loss of the Quaternary record preserved in the cliffs. Erosion will also impact on slope morphology, affecting invertebrate species. Inland outcrops of geological interest could also be obscured by slumping and mass movement, reducing the significance of their interest.

This increase in sediment input may however help to maintain beach levels along the low lying beach frontage of Sea Palling, Horsey and Winterton to the south (Dickson and others 2007). However, sea level rise and increases in the frequency and severity of storms are likely to outweigh such benefits. The sandy beaches, a key tourist attraction in the Character Area are likely to be diminished over time without continued human intervention in the form of groyne replacement and ongoing beach feeding. Current beach management activities cost between £1.5 to £2 million per year. It is important to look at the coast as a system; changes in physical processes in one part of the system are likely to have consequent effects elsewhere.

The Broads lacks the characteristics of landscapes robust to climate change (see Box 3.2). Whilst it exhibits diverse water regimes and diverse vegetation the area lacks topographic variation. This lack of variation in land height outweighs the benefits of diverse water and vegetation regimes. Consequently, there is nowhere for species to migrate to in response to climate change. The low-lying nature of the Broads makes it highly vulnerable to sea level rise and saline intrusion. The Broads is thus highly vulnerable to climate change and cannot expect to be robust to its impacts without adaptation.

Box 3.2 Resilience and robustness to climate change

When evaluating the impacts of climate change on landscapes, the terms robust and resilient are potentially useful. However, there are subtle differences between the terms. Resilience is defined in the climate change literature as '*the ability of a system to recover from the effect of an extreme load that may have caused harm*' (UKCIP 2003) whilst robustness is defined as '*the ability of a system to continue to perform satisfactorily under load'* (UKCIP 2003). In terms of climate change and the natural environment, a resilient landscape can be thought of as one that can recover following an extreme climate event (such as a storm or flood) although recovery may not be to the same condition as it was in prior to the event. Recovering from climate change will involve a shift in state; recovery to the status quo will not be sustainable in the long term.

A robust landscape can be thought of as one that continues to function under the stresses caused by prolonged changes in temperature and rainfall. In order to continue functioning a robust landscape must posses the ability to change in response to climate change e.g. species need to be able to move. A robust landscape is likely to possess extensive, permeable habitat networks and exhibit heterogeneity within and between habitats. Landscapes robust to climate change are likely to possess the following features (Hopkins and others 2007):

- High permeability;
- Variation in topography – slope, aspect and height;
- Soil diversity;
- Numerous land cover types;
- Diverse and structurally varied vegetation;
- Diverse water regimes.

Indirect impacts

Changes in agricultural land use in response to climate change may alter the appearance and character of the landscape more than direct impacts of climate change. It could also pose a risk to some archaeological landscapes and buried archaeological sites. Table 3.3 demonstrates that it is likely that impacts on agriculture will also have an impact on the landscape of the Broads in future. For example, re-intensification of agriculture due to improved growing conditions and new viable crops may result in increased field size with consequent ditch infilling and a monoculture landscape at the expense of the wetland and grassland networks. Changes in grazing in response to an altered pattern of vegetation growth may also change the appearance of the Broads landscape. Summer drought and the need to maintain water levels within the ditches to retain stock may require engineering schemes to capture more water from rivers and store winter rainfall for summer use. Such a scheme has already been delivered for Halvergate Marshes at a cost of £1.3 million.

Maintenance of much of the agricultural activity within the floodplain is also dependant upon continued flood risk management. Over time earth embankments will have to increase both in height and footprint. Material for these embankments is likely to be won locally resulting in wide channels (soke dykes) at the hind of these banks. The improved banks will be reseeded and regularly mown. The result is a change to the traditional Broads landscape.

Habitat creation in response to climate change will impact on the landscape of the Broads. Freshwater and wetland habitats, some of these of European importance, will be lost from the Broads due to climate change. In some cases they may be relatively easy to recreate elsewhere, such as reedbed and grazing marsh. Others such a fen and alder woodlands on deep peat soils may well be un-recreatable. However over time it will become increasingly difficult to maintain such a habitat suite within parts of the Character Area as climatic and water conditions will no longer be suitable to sustain them. There may be opportunities to generate new freshwater wetlands in the upper most reaches of the Broadland rivers. These however will be limited in extent due to the narrowness of the valleys. New wetlands upstream of Norwich, though outside the Character Area could reduce flood risk for urban Norwich. However it is probable that large freshwater wetlands to replace the longer term losses in the Broads would need to be created elsewhere in places such as the Fens. Within the Broads however, over the longer-term there may be scope to re-create inter-tidal and brackish habitats lost from areas outside the Broads. This would result in an increase in estuarine and brackish reedbed habitats within the landscape.

Habitat creation, managed realignment of current defences and new defences can pose a risk to archaeology, buildings and landscapes. It is important that in any future decision making it is recognised that the historic environment is finite, and a non-renewable environmental resource in its own right.

Changes to the Broads landscape may alter people's perception of the area. The open water bodies, wetland habitats and grazing marshes of the Broads are, to many people, an iconic landscape. Changes to this iconic landscape may impact on recreation and tourism.

Table 3.3 Impacts of climate change on landscape

Landscape feature	**Impact of climate change**
Shallow open water bodies	Flooding in winter. Drying out in summer – exposure of draw down zone. 'Forward switch' to turbid, algal dominated state. Increase in rate of scrub encroachment and vegetation succession in situations isolated from rising river levels. Increased fetch will create hard visual interface between water and land.
Carr woodland	Changes in species composition. Drying out in summer. Possible loss of some wet woodlands but gain of scrub elsewhere.
Drained peat areas	Possible loss through sea level rise, fluvial flooding and marine incursion. Loss of diverse ditch communities and replacement with visually simple ones, possibly dominated by invasive aliens. Increased risk to some archaeological landscapes and buried archaeological sites.
Estuarine marshland and grazing marsh	Possible loss through sea level rise, fluvial flooding and marine incursion. Changes in species composition. Loss of diverse ditch communities and replacement with visually simple ones, possibly dominated by invasive aliens. Increased risk to some archaeological landscapes and buried archaeological sites.
Fen	Loss through sea level rise, fluvial flooding and marine incursion/intrusion. Drying out in summer. Species change. Increase in rate of scrub encroachment and vegetation succession in situations isolated from rising river levels.
Estuary	Conversion of brackish reedbed to saltmarsh. Drowning out and erosion of some saltmarsh areas.
Heathland	Possible loss through sea level rise and marine incursion. Changes in species composition.
Dunes and coastal levels	Loss of dunes due to sea level rise. Loss of historic environment due to sea level rise. Erosion of sandy beaches and dunes.

3.3.4 Impacts on ecosystem services

Direct impacts

Table A3.4 in Appendix 3 identifies the significant ecosystem services offered by the Character Area. Reduced summer rainfall and more intense rainfall events in winter will impact on the water resources available for agriculture, recreation, potable water supply and habitats. Increased demand as a result of hotter, drier conditions will compound this issue, potentially resulting in a supply-demand deficit. The Environment Agency's Catchment Abstraction Management Strategy already describes the majority of the Broadland catchments as over abstracted, over licensed or with no water available. Only two units are considered to have water available; the River Chet and the Broads chalk groundwater.

Agriculture will be indirectly affected by climate change through reduced water resources but it also faces direct impacts. The types of crops and livestock supported by the Broads will be altered by climate change; current crops may not be able to persist under hotter, drier conditions but new, drought tolerant crops may thrive. It is likely that new pests and diseases will be present as a result of warmer conditions and this may directly impact on agriculture. This may also impact on human health if vector borne diseases such as malaria or tick borne diseases become prevalent in the area.

Maintenance of most agriculture in the Broads requires continued investment in maintenance of flood embankments, drainage infrastructure and land drainage pumps. Over time such activities will become more difficult as a result of the impacts of climate change and more costly. The current Broads Flood Alleviation Scheme will maintain the embankments within the Broads until 2021 at a current cost of £120 million.

Fisheries will be directly impacted by climate change. The fish species supported by the Broads are likely to change as water temperature increases and dissolved oxygen levels decline. Stocks of traditional species may decline but may be replaced by newly viable species such as carp. There may also be seasonal changes in fish movements and spawning.

Picture 3.2 Sandy beach in the Character Area

Recreation and tourism will both be directly affected by climate change. The risk of flooding, an increase in pests or a decrease in water quality may threaten the attractiveness of the area to visitors. An increase in erosion at the coast could reduce the extent of sandy beaches and dunes (see picture 3.2). This could have negative impacts on recreation as they are significant tourist attractions.

A reduction in beach height and extent could also have implications for coastal flooding as the beaches currently protect sea defences from erosion.

An increase in the rate of physical processes could impact on the soils of the Character Area. There is a risk that soils will be more easily lost through increased erosion due to increased run-off throughout the Broads catchments. This will result in increased sedimentation and declining water quality in the Broads. Diffuse inputs currently adversely impact the water quality of the Broads so that environmental objectives are not met. Increased erosion will also impact on the historic environment of the Character Area as the most recent history and archaeology are preserved in this upper soil layer. Palaeolithic archaeology has also been found in the cliffs at Happisburgh and would be vulnerable to an increase in erosion. An increase in the rate of fluvial processes could lead to river channel migration and consequent impacts of sedimentation, navigation, flood management and the landscape.

An increase in soil erosion and loss of biomass as a result of climate change may impact on the climate regulation function of ecosystems. Carbon is stored in soils, particularly the peat soils of the Broads floodplain, and its vegetation; loss of these will accelerate the release of carbon dioxide, exacerbating climate change. Further work is required to understand fully the fluxes of green house gas emissions from wetlands. Wetlands however may emit carbon dioxide, methane and nitrogen dioxide in significant quantities, depending on a variety of characteristics such as age, land-use prior to flooding, climate, and management practices. Emissions vary spatially and over time. Nitrous oxide emissions from wetlands are typically very low, unless there is a significant input of organic or inorganic nitrogen from the catchment. Where new wetlands are to be created on previously cultivated peat, even after taking account of the increases in methane, the overall result may be a net benefit due to the reduction carbon dioxide and nitrogen dioxide emissions.

Indirect impacts

Indirect impacts of climate change will also be felt by ecosystem services. The recreational and tourism services offered by the area are at risk of being negatively impacted by an increase in visitor numbers. As well as an increase in recreation and tourism, the use of the Broads for outdoor educational purposes is likely to increase as conditions become warmer and drier. Trampling and footpath erosion are likely consequences of an increase in visitors. This may result in the need for 'hard' and potentially more intrusive access provision. An increased human presence in the landscape will also result from an increase in visitor numbers and this may negatively affect the attractiveness of the Broads for recreation and tourism. A further indirect impact of an increase in visitor numbers is increased pressure on water resources, water quality and infrastructure, exacerbating direct climate impacts (see Section 3.3.2).

3.3.5 Socio-economic impacts

Climate change is not the only cause of change in the natural environment of the Broads. Agriculture and recreation changes will have a significant impact on the biodiversity, access and recreation and landscape and geodiversity assets of the area. Changes in these sectors are hard to predict as there is no certainty over which socio-economic scenario will prevail in the future (see Appendix 2). Table A3.5 in Appendix 3 provides some examples of socio-economic impacts, which could affect the species, habitats, landscapes and recreational function of the Broads Character Area. This is based on knowledge of socio-economic changes, informed by current trends and drivers (e.g. the Water Framework Directive; European and United Kingdom Climate Change Programmes) and the futures literature (e.g. Evans and others 2004; LUC and others 2006; OST, 2002; UKCIP, 2001).

Potential changes in the agricultural sector are likely to have significant impacts on the Character Area. Changes in crop markets will have a significant impact on land use within the Broads. For example, if the market for energy crops becomes favourable, farmers may switch from food production to energy crop production with resulting impacts on biodiversity and landscape. Alternatively, a rising population may increase the demand for food crops, potentially resulting in re-intensification of agriculture in the Broads, particularly on grazing marshes.

One important socio-economic change may be a shift in consumer demand towards more organic and local produce. This growth is already being seen, for example Broadland beef, and may continue in future as people become more concerned with where their food comes from and how it is produced. This socio-economic change could have benefits for biodiversity; a reduction in pesticide use may increase invertebrate populations which will have a beneficial impact on bird species. In addition, a reduction in the use of artificial fertilisers will have benefits for water quality and nutrient loading.

The Environment Agency is currently undertaking a programme of flood bank improvement to maintain the standard of flood risk management in the Broads. This may result in an increase in the area of arable land behind the improved banks as farmers perceive their land to be at lower flood risk from breach. If it were to happen this is likely to impact on the biodiversity and landscape of the Broads. Many farmers are currently under ESA agreement thus preventing such a change. However many of these agreements will come to an end in 2012, at which time landowners will reconsider their options.

Changes in the water industry such as an increase in water metering or the introduction of variable tariffs could also have benefits for the natural environment. Through managing demand for potable water, these initiatives could lead to greater water availability for non-potable uses such as maintenance of traditional grass marsh agriculture and wetland habitat creation and restoration, beyond the environmental demands already taken into account. There may be competition for such water from intensified agriculture.

Growth in population in the East of England could put further pressure on the Character Area as demand for housing, recreation, transport and other infrastructure would increase. Whilst designated areas such as the Broads and the Area of Outstanding Natural Beauty may be protected from most development under prevailing legal and socio-economic conditions, other areas within the Character Area may be further fragmented by development and other related land use change which may inhibit delivery of habitat networks.

Climate change mitigation is largely driven by Government policy e.g. the United Kingdom Climate Change Programme (UKCCP). In addition to direct and in-direct impacts of climate change, assets can be impacted by mitigation policy. Currently, United Kingdom climate and energy policy supports the development of wind power in response to climate change. The east coast is already being used for off-shore wind farms eg Scroby Sands; further development of wind power could impact on the landscape of the Broads and the Norfolk Coast AONB. Mitigation policy also favours the growth of energy crops. This could also have an impact on the Broads if it leads to re-intensification of agriculture (see above).

3.3.6 Policy implications

A change in species and habitat composition may affect the delivery of current conservation targets which include definitions of ‘good quality’ and ‘favourable condition’. Under current, static definitions of ‘quality’, species and habitat compositional changes may make it more difficult to meet targets as climate changes. In addition, a potential increase in non-native and invasive species may threaten the delivery of conservation objectives.

4. Adaptation

Box 4.1 Key adaptation responses

- The expected impacts could be lessened if adaptation is undertaken. Such adaptation range from short-term adaptation responses to possible long-term scenarios.
- Discussions have already commenced on the longer-term future vision for both the coast, via the Shoreline Management Plan (3b) and the Broads as part of the Broads Plan. This report focuses on adaptation actions in the short term.
- It is critically important that efforts are maintained to continue to restore, maintain and enhance the natural environment of the Broads, thereby making it more robust to future change.
- Being aware of future potential catastrophic events such as storms or pests and diseases that may occur or be exacerbated as a result of climate change.
- Extension of existing habitats and the creation of new areas. There may be limited opportunities in the Broads to recreate freshwater habitats as the area of suitable climate space declines. However, there will be increasing scope within the Broads to create brackish, transition and inter-tidal habitats.
- Assess the likely increase in visitor numbers and identification of areas in the Character Area most at risk from the negative impacts of recreation.
- The provision of shade and drinking water at tourist attractions will be important. If necessary, place restrictions on water based recreation during periods of poor water quality.
- In addressing impacts on water resources and water quality it will be necessary to manage catchments in a more holistic manner.
- Catchment sensitive farming methods to protect soils and water.
- Use the spatial planning system to maintain adequate land for the natural environment.
- Identifying research needs and commissioning appropriate studies - an early step towards building adaptive capacity that should increase the effectiveness of strategies when implemented.

The previous chapter highlights the likely impacts on the natural environment of the Broads if no adaptive management is undertaken. However, the expected impacts could be lessened if adaptation is undertaken. Such adaptation range from short-term adaptation responses to possible long-term scenarios.

This report identifies the important wildlife, landscape and recreational features, what might happen to them through climate change and what our possible responses could be. As a body set up to conserve and enhance the natural environment for current and future generations, Natural England sees it as vital that we consider the implications of climate change for the natural environment and how best to respond.

Climate change is already happening, and the Broads will be increasingly affected, so the intention of this document is to prompt discussion of the immediate actions open to us. The longer we put off such discussions, the fewer options will be available.

Many aspects of climate change are likely to have a significant impact on the structure and functioning of the Broads Character Area. The scale of the potential impacts of climate change on the Broads, in relation to sea level rise, necessitates wide-ranging adaptation. This report focuses on adaptation actions in the short term. These responses have been informed by Hopkins and others 2007, who present guidelines for conserving biodiversity in a changing climate (see Box 4.1). Discussions have already commenced on the longer-term future vision for both the coast, via the Shoreline Management Plan (3b) and the Broads as part of the Broads Plan. The former being led by North Norfolk District Council and overseen by the Environment Agency and the latter by the Broads Authority. It is not the intention, nor the role, of Natural England to make decisions about the long-term future of the Broads. We recognise that those decisions must take into account many considerations of which the future of local communities is a vitally important one. However, it is our role to try and understand the implications for the natural environment and to advise accordingly.

4.1 Adaptation responses

Action will be required to adapt to sea level rise and other aspects of climate changes. Such action at the site level needs to be implemented immediately to increase the resilience of existing features to climate change.

Based on the impacts identified in Section 3, a list of adaptation responses for the Broads has been complied (see Table A3.2, Appendix 3). These have been informed by Hopkins and others 2007, who present guidelines for conserving biodiversity in a changing climate (see Box 4.2). It should be noted that the Hopkins and others (2007) guidelines apply only to terrestrial habitats and may be less applicable for some of the Broads habitats. It is also important to consider the timescales in operation. For example the first guideline (conserve protected areas and other high quality habitats) is a wholly justified approach. This includes Natural England's continued investment in environmental outcomes within the Upper Thurne basin via agri-environment schemes, currently £1.6 million a year. However depending upon the decisions made in future years by others, there may come a time when this may not be so. The guidelines however, provide a sound basis for implementing climate change adaptation in the Broads for at least the short term and in the majority of instances probably into the medium term and beyond. It is critically important that efforts are maintained to continue to restore, maintain and enhance the natural environment of the Broads, thereby making it more robust to future change.

When defining adaptation actions, existing schemes, strategies and levers need to be considered. Some actions defined as climate change adaptation are already occurring under a different name and it may be possible to modify existing programmes to provide a mechanism for delivering adaptation. Climate change adaptation will be incorporated into existing Natural England plans and policies such as Higher Level Stewardship, but also those of other organisations.

It should be recognised that there may be policy, economic or other constraints to delivery of some actions; these are identified in Table A3.2. Additionally, some of the actions identified may not have a delivery mechanism at present. At this stage, all potential adaptive actions are included despite known constraints.

Box 4.2 Guidelines for conserving biodiversity in a changing climate, Hopkins et al. (2007)

1. Conserve existing biodiversity;
- *i.* Conserve protected areas and other high quality habitats;
- *ii.* Conserve range and ecological variability of habitats and species;

2. Reduce sources of harm not linked to climate;

3. Develop ecologically resilient and varied landscapes:
- *i.* Conserve and enhance local variation within sites and habitats;
- *ii.* Make space for the natural development of rivers and coasts;

4. Establish ecological networks through habitat protection, restoration and creation;

5. Make sound decisions based on analysis:
- *i.* Thoroughly analyse causes of change;
- *ii.* Respond to changing conservation priorities;

6. Integrate adaptation and mitigation measures into conservation management, planning and practice.

4.1.1 Biodiversity responses

Direct impacts

A number of management practices are suggested in Table A3.2 that aim to maintain and enhance current significant natural environmental assets in the Character Area through adaptive management. Adaptive management involves modifying existing management practices in the face of uncertainty, in this case due to climate change. The approach involves making a change to an existing management practice and monitoring the results to ensure the response is effective. As a result of monitoring, the management practice may need to be reviewed again. Examples of adaptive management in the Broads include:

- Altering timing and duration of grazing to responds to changes in biomass availability;
- Extensification of grass marsh agriculture;
- Altering hay cutting date to respond to phenological changes;
- Creating new wetland to moderate water level on existing wildlife sites;
- Blocking coastal drains to reduce sea water ingress;
- Raising water levels in the Upper Thurne basin to reduce sea water ingress;
- Creating fish refuges;
- Identifying and implementing adaptive dredging depths throughout the rivers.

Adaptive management has a number of advantages over more radical solutions. It is relatively inexpensive as it is already an ongoing process which needs modification rather than a step change in approach to management. It is also a flexible approach and that should be able to quickly respond to change, assuming the change is gradual rather than a series of large shifts. As the impacts of climate change are uncertain, there is value in taking a step-wise approach to adaptation. Under a programme of adaptive management, the results of each action can be analysed against prevailing climate and socio-economic conditions before proceeding to the next stage. The intended result is a landscape that gradually becomes more robust to the impacts of climate change. Taking this approach can also be seen as a more prudent use of resources.

Wetland proposals over areas such as north and south of Hickling Broad and within Heigham Holmes are wholly consistent with an adaptive management approach. Indeed delivery of such projects could act as a demonstration for adaptive management of floodplains and also provide an additional example of Natural England's continued commitment to the Upper Thurne and the Broads more generally. They also provide an opportunity to demonstrate integrated delivery whereby environmental, social and economic benefits are delivered. The experience at places such as Glebe Marsh shows the way 'new' nature can be developed on areas of previously drained floodplain (picure 4.1).

Photo credit (Mike Page)

Picture 4.1 View of the Roman fort at Burgh Castle and Glebe Marsh

A direct impact of warmer conditions is an increase in the prevalence of pests, diseases and invasive species within the Character Area. A common response across all habitat types is the need to be aware of future potential catastrophic events that may occur or be exacerbated as a result of climate change such as the emergence of new pests and diseases. This response requires ongoing monitoring of species and habitats at the same time as preparing contingency plans. It is important that lessons from previous events such as the storm of 1987 and Dutch elm disease are learnt and that past experience is used to inform the development of future management responses. We can also look to other locations with similar climates to that which England may experience in future to identify potential threats.

In addition to maintaining existing habitats, a number of responses (see Table A3.2) advocate the extension of existing habitats and the creation of new areas. This is the fourth of the Hopkins and others (2007) guidelines (see Box 4.2). The extent to which plants and animals can move in order to adapt to the effects of climate change will be an important factor in their continued persistence at specific locations (Catchpole 2007) thus increasing the area of suitable habitat is likely to aid the conservation of species. Increasing the area of habitat is worthwhile because larger populations are less likely to go extinct from random events.

In order to maintain the same degree of biodiversity in the face of climate change, more habitat is required. One way to do this is to extend the existing habitat networks in the Broads (see Box 4.3). Habitat networks can be extended at the habitat scale through habitat restoration and re-creation. They can also be enhanced by improving the connectivity between habitat blocks. This is important in the Broads where the floodplain has been hydrologically divided in more than forty units.

However, creation of ecological networks cannot prevent biodiversity loss due to climate change, it can only reduce it and there is a danger of spending resources re-creating habitats that will not be sustainable under a changed climate. Similarly, habitat re-creation targeted at specific species may not be an effective response if the species is likely to be lost as a result of climate change (see Section 4.1.2).

Box 4.3 Extending Habitat Networks

The England Habitat Network (EHN) illustrates the existing networks of woodland, grassland, heathland and mires and bogs present in England. A habitat network is made up of current statutory sites and sites listed on habitat inventories and surrounding land that is potentially permeable to the species present in the habitat of interest. Different types of land use, in-between patches of semi-natural habitat, will have different levels of permeability for different species (Catchpole 2007); the network joins up those sites which are separated by potentially permeable habitat or land use.

To maintain the same degree of biodiversity in the face of climate change, more habitat is required. With regard to the EHN there is a need to prioritise habitat creation action (highest priority action at the top):

- Subject to 'ground truthing', aim to maintain the existing mapped EHN for its value as an aggregated area of existing habitat patches;
- Consider extensions/additions to the habitat patches, including the expansion of pinch-points, within the EHN;
- Expanding existing habitat patches in networks outside the EHN;
- Expand small isolated patches in 'hostile' environments.

There may be limited opportunities in the Broads to recreate extensive areas of freshwater habitats as the area of suitable climate space declines. More sustainable sites outside the Character Area boundary will need to be found to recreate the freshwater features that may be lost as a result of climate change. Under current European legislation, Governments are responsible for maintaining the European protected site series (SAC and SPA) in a favourable condition, ensuring no net loss occurs. Clearly climate change presents a European and nation-wide threat to this trans-national biodiversity resource. This European-wide issue lies outside the scope of this report. However consideration of what might be required in the Broads is relevant. If there were direct impacts and or losses to these designated sites then a mitigation package would need to be developed. This might include modification to existing sites and the recreation of replacement habitat elsewhere. Some of the habitats present within the Broads are currently thought un-recreatable, and this factor needs to be taken into account during future decision making. Better understanding of the re-creatability and sustainability of the range of habitats and species that might be lost is required. It may not be feasible or sustainable to recreate such freshwater habitats in the Broads due to climate change. It is likely that such habitats will be located beyond the Broads boundary in places such as the Fens. A 50-year Vision for wetlands (2008) has confirms the current wetland interest in the Broads (see Figure 2.4) but also highlights the huge potential for wetland creation in the Cambridgeshire Fens. Further research on this issue would be required to fully assess the feasibility of such a programme of action. However in the interim it is important that a programme of habitat creation to off-set these future losses is progressed, for it is expected to take many years for these new sites to acquire the desired biodiversity interest, even if this is achievable. However, over time there will be increasing scope within the Broads to create brackish, transitional and inter-tidal habitats. Losses of these habitats from areas outside the Broads can be compensated within its boundary.

While the above considers the possible actions required for designated site interest, there are additionally large areas of priority Biodiversity Action Plan habitats and species. Currently there is a lack of clarity as to how these interests would be considered under a scenario of climate change.

Indirect effects

In the Broads it is very important that existing habitats are brought up to favourable condition in order that they can be resilient to climate change. Climate change will exacerbate existing pressures and may be a 'tipping point' that prevents habitats recovering. Wetland and freshwater habitats in particular are subject to many pressures other than climate change and these must be addressed. A number of pressures that need addressing are identified in Table A3.1 including abstraction, nutrient enrichment, drainage and isolation of wetlands, sediment loading and invasive species. A number of responses are suggested:

- Increasing the ability of catchments to retain water through floodplain planting of wet woodland, restoration of water meadows and introduction of permeable surfaces.
- Restoring the structure and function of river channels.
- Restoring connectivity between river channels, their floodplains and wetland habitats.
- Reduce sediment loading through catchment sensitive farming.

There are a number of existing pressures on coastal habitats that need addressing in order to increase climate change resilience. Responses to these additional pressures identified in Table A3.2 include:

- Reduce abstraction and drainage from within the coastal zone.
- Block coastal drains to reduce salt water ingress.

Indirect impacts of climate change on the Character Area will also be felt through changes in agricultural practice and recreation (see Section 4.1.2). A number of adaptive management responses can be used to respond to changes in agriculture but the main tool for ensuring the maintenance of the natural environment in the face of agricultural change will be agri-environment schemes. A number of responses identified in Table A3.2 can be delivered through environmental stewardship schemes.

4.1.2 Access and recreation responses

Direct impacts

The impacts of climate change on fish stocks could be mediated in the short term by the creation of fish refuges. Estuarine fishing could be marketed to anglers as an alternative to river fishing. Estuarine fish are likely to become more abundant and this would alleviate pressure on freshwater fish.

An increase in summer heat related illnesses may be significant and the area should ensure that is has an up-to-date heat wave contingency plan. The provision of shade and drinking water at tourist attractions will be important. It will also be necessary to assess water quality in summer and if necessary, place restrictions on water based recreation during periods of poor water quality.

Flooding is a direct impact of climate change on recreational assets. It may be necessary to put in place temporary diversions or closures of rights of way during flood events. The success of this will depend on agreement with land owners, the highways authority and how well the re-routing is publicised. Communication with local recreation groups will be necessary to ensure this response is successful. It would be possible to prevent damage to rights of way on the floodplain and adjacent to water courses by raising them using embankments and bridges. However, this would be highly costly and would be unsustainable in the long term. An alternative strategy is to create alternative routes on rising land adjacent to the floodplain. These landward footpaths would be at a lower risk of flooding and could provide year round access. Boatyards will need to adapt to changing hydrological regimes.

Indirect impacts

The most significant impact of climate change on access and recreation is likely to be an increase in visitor numbers. This can be seen as an opportunity for recreation as more people will be able to enjoy the countryside. However, this opportunity may present risks to significant natural environmental assets if it is not managed appropriately. The suggested responses to an increase in visitor numbers are thus aimed at reducing negative impacts and ensuring recreation and tourism can flourish within the area in a way that is sustainable.

A key part of any visitor management strategy must be an assessment of the likely increase in visitor numbers and identification of areas in the Character Area most at risk from the negative impacts of recreation. Currently, there are few records of current and historic visitor numbers and types of visitors; systems for gathering this data should be established so that it can be used to predict increases and monitor change.

Modelling of visitor numbers and temperatures could also be undertaken to indicate the likely scale and timing of visitor number increases due to climate change. Once an indication of visitor numbers has been obtained, they can be theoretically allocated to visitor attractions based on previous experience, relying on the assumption that the factors attracting visitors remain constant over time (Table A3.2). With this information, a risk assessment of those areas most at risk of disturbance to wildlife, footpath erosion, congestion, trampling etc can be made and adaptive management techniques deployed accordingly. This initial research is key to effective visitor management and allows a tailored approach to be undertaken at vulnerable sites.

It may be possible to spread the impact of an increase in visitor numbers across the Character Area. Burden sharing is a generic adaptation to climate change which can be applied to recreational assets in a natural environment. Currently, certain elements of the Broads are considered most desirable to visitors and there is a high demand for access and recreational services. These ‘honeypots’ include Hickling Broad, the broads between Wroxham and Ranworth, Sea Palling and certain rights of way. As demand for recreation increases it is likely that these sites and routes will reach or exceed their carrying capacity. In response to this, it is suggested that alternative sites and routes are publicised in an attempt to spread demand throughout the less sensitive parts of the area.

However, dispersal of visitors may create more problems than it solves, particularly in terms of biodiversity impact. It may be better to concentrate visitors at honeypot sites with existing visitor facilities. The need for quiet refuges for sensitive wildlife on the floodplain will need to be maintained.

It will be important to link any access and recreation responses with development in the Norwich Growth Point and its Green Infrastructure Strategy, and regeneration in Great Yarmouth and Lowestoft. An advertising campaign based in these urban areas which serve as a gateway to the Broads for visitors, may help to disperse people more widely between attractions and draw their attention to less well known and more robust sites. Another technique would be to provide and promote circular walks from urban areas, thus reducing the numbers of people in the more sensitive parts of the Broads and reducing the need to travel for recreation. The Whitlingham Country Park is a good example of providing opportunities for people to experience the Broads without the need to travel far from urban Norwich. Further opportunities to provide similar ‘gateways’ for Great Yarmouth (Broadlink/Runham Broads) and Lowestoft (Carlton Colville) exist.

In order to avoid congestion, pollution and other negative impacts of an increase in vehicle movements within the Broads, it is felt that improvements to public transport facilities will be needed. Public transport initiatives within the Broads need to be integrated with other modes of transport, including the railways, waterways and roads serving gateway destinations to the Character Area.

4.1.3 Landscape responses

The landscape response in the Broads will be determined by the strategic management employed to adapt to sea level rise. However, there may be significant changes in the landscape as a result of adaptation to other impacts.

Restoring and creating new areas of habitat or extending existing ones will have an impact on the landscape of the Broads. Whilst habitat creation is undertaken at the local scale, the aggregate impact of habitat creation may change the appearance of the wetland at the landscape scale. It is likely that freshwater habitat will be replaced by brackish, transitional and inter-tidal habitats in the Broads as freshwater habitats become less sustainable. However, some habitat creation in the form of floodplain restoration, may have a positive impact on the landscape character of the Broads. Habitat creation may also be beneficial in terms of reducing soil erosion and improving water quality. Another expected change would be a reduction of woodland elements within the landscape and an increase in open water and 'big sky' principally where new wetlands are created.

The historic landscape of the Broads will be impacted by climate change. It is a finite and non-recreatable resource in its own right, and the Broads possesses many valued assets. These need to be taken into account in any future evaluation or decision making. A 'record and rescue' programme should be implemented to identify historic environment assets most at risk from the impacts of climate change. Where possible these assets should be protected or, if that is not feasible they should be recorded. There may be conflict between habitat creation designed to address the impacts of climate change on biodiversity and landscape and historic landscape assets. The significance and integrity of important historic assets can be threatened by poorly designed adaptation responses. An integrated approach is therefore required when assessing potential adaptation within this Character Area. For example:

- Planting of wet woodlands on floodplain. These areas may be characterised by water meadow systems, which would be damaged by such planting. Flood meadows can represent a good way of controlling and storing water, and it might be better for the historic environment, the historic landscape, the overall landscape character, if these are restored rather than creating wet woodland.
- Altering the number of grazing animals in response to increased grass growth - can lead to poaching and erosion of archaeological remains.

Increases in the rate of physical processes are likely to impact on geological assets. A similar 'record and rescue' programme to that suggested to protect historic landscape assets could be implemented to identify geodiversity assets most at risk from then impacts of climate change.

It is important to look at the coast as a system; changes in physical processes in one part of the system are likely to have consequent effects elsewhere. In order to better understand sediment transport and changes to physical processes it may be necessary to conduct further modelling research.

4.1.4 Ecosystem Service response

Climate change will impact upon the ecosystem services offered by the Character Area and effective responses must be employed to protect them. Table A3.3 suggests potential responses to impacts on ecosystem services in the Broads. Many of the responses described under biodiversity, access and recreation and landscape responses will have multiple benefits in preserving ecosystem services.

Water is a significant feature in the Broads and it provides ecosystem service in terms of water resources and recreation. In addressing impacts on water resources and water quality it will be necessary to manage catchments in a more holistic manner. Management practices upstream have impacts downstream. In response to reduced water availability it would be beneficial to increase water storage capacity within the catchment and to reduce the rate of overland flow. This also has benefits for flood protection as water takes longer to reach the channel, thus avoiding high peak flows. There are also benefits for wetland habitats at risk of drying out as a result of climate change.

In response to water shortages, farmers may need to increase their capacity for on-farm water storage. Sensitive farming methods including leaving vegetated buffer strips around fields and not leaving fields bare will improve water resource availability and water quality. Catchment sensitive farming methods to protect soils will also have long term benefits for ecosystem services in the face of climate change. Farmers will need to be aware of the potential for different crops and livestock but also new pests and diseases which could threaten their livelihood.

Water also provides a significant service for recreation; the rivers and broads are the main tourist attraction in the area. The attractiveness of the Broads may be reduced as water levels change or water quality reduces. Managing the increase in visitor numbers will be crucial to maintaining the water environment so that it remains attractive and continues to provide a service in terms of recreation.

Many of the responses suggested to adapt to the impacts of climate change on biodiversity will have benefits for climate regulation. Increasing the area of semi-natural vegetation will increase the vegetation carbon store. It will also stabilise soils, reducing soil erosion and protecting the soil-carbon store.

4.1.5 Response to other socio-economic impacts

Table A3.4 in Appendix 3 sets out responses to the likely socio-economic impacts.

Climate change may be the ‘tipping point’ that prevents the wetland from recovering from the in-combination effects of all sources of pressure. In addition, the legacy of past sources of pressure on the natural environment may restrict the ability of the area to adapt to climate change. It is thus vitally important that efforts are made to address other sources of pressure in order that habitats are more resilient to climate change. This is the Hopkins and others (2007) second guiding principle for adaptation to climate change (see Box 4.2).

Potentially the biggest socio-economic impact on the Broads will be an increase in tourism and recreation. Increases in recreation are likely irrespective of climate change as the population of the East of England increases and tourism is likely to increase as more people choose to holiday in the United Kingdom (see responses suggested in Section 4.1.2).

As many of the socio-economic impacts will be felt through an increase in development pressure (for housing, transport, wind turbines etc) both within and adjacent in the catchment, the main response is to use the spatial planning system to maintain adequate land for the natural environment. It is also important the growth is within the environmental capacity for the area. It has already been identified that more habitat is needed in order for the natural environment to adapt but there will be competing pressures for land. Whilst there is no certainty over what the natural environment will look like under conditions of climate change, it is certain that more land will be required. The spatial planning and landscape designation systems must be used to ensure that land is available in future for the extension of networks.

Some of the socio-economic changes identified in Table A3.4 may have beneficial impacts on the Broads. These opportunities must be recognised and acted upon in order for the natural environment to derive maximum benefit from changes occurring in other sectors.

4.1.6 Policy response

A common impact across all habitat types is the likelihood of species and habitat compositional changes and there is a need for policy to reflect this. Changing conservation objectives may require a radical shift in the current paradigms of conservation; non-native species may have to be favoured and the attitude towards alien and invasive species may have to change. Currently, species such as Canadian pondweed are seen as negative indicators which reduce the available space for more highly valued native species. However, if native species are less viable under conditions of climate change, attitudes towards non-natives may have to change. Is it possible that species currently considered of low conservation value in the United Kingdom, and indeed invasives, may become so rare in their native habitat that the United Kingdom has a responsibility to conserve them.

Potentially a more important and widespread case will be that the species/habitats currently considered characteristic of the Broads will change in abundance; the new assemblages will still be mainly native British species, but different. Conservation policy needs to change in response to changing habitats.

Responding to the impacts of climate change may be hindered by incomplete information. For example, in order to respond to the impact of a decrease in summer rainfall on wetland habitats, research into local hydrology is required. The fifth Hopkins and others (2007) guideline for adaptation states that sound decisions should be based on analysis. Identifying research needs and commissioning appropriate studies can be seen as an early step towards building adaptive capacity that should increase the effectiveness of strategies when implemented.

Policy responses will also be necessary to reduce sources of pressure other than climate change. Whilst it is possible to recognise that policy change will be required, future policy can not be prescribed as it will be mediated by the prevailing socio-economic scenario; attitudes to the environment, energy generation and development will all be dependent on socio-economics.

5. References

A 50-year Vision for wetlands. Securing a future for nature, people and the historic environment. The Wetland Vision partnership, 2008. *www.wetlandvision.org.uk*.

Broads Authority, 2004. Broads Plan 2004 – A strategic plan to manage the Norfolk and Suffolk Broads. Broads Authority, Norwich.

Carter, I. and Tolhurst, S. 1994. *Broadland SPA Departmental Brief*. English Nature.

Carter, I. and Tolhurst, S. 1994b. *Broadland Ramsar site citation*. English Nature.

Catchpole, R. *England Habitat Network. Briefing Note*. Natural England, Sheffield .

CQC, undated. Available at http://www.cqc.org.uk/jca/Consultation/Default.aspx?CqcJcaID=64.

Davies, Z.G., Wilson, R.J., Coles, S. and Thomas, C.D. 2006. 'Changing habitat associations of a thermally constrained species, the silver-spotted skipper butterfly, in response to climate warming'. *Journal of Animal Ecology* 75, 247–25.

Defra, 2005. *Adaptation Policy Framework A consultation by the Department for Environment, Food and Rural Affairs* Defra, London.

Dickson, M.W., Walkden, M.J.A. and Hall, J.W. (2007) Systematic impacts of climate change on an eroding coastal region over the twenty-first century. *Climatic Change* 84, 141-166.

Doarks, C. (1990) Changes in the flora of grazing marsh dykes in Broadland, between 1972-74 and 1988-89. *England Field Unit Project 76.* Nature Conservancy Council, Peterborough.

ELP, Ecology Land and People (2005) *Feasibility Study for Solutions to the Salinity and Ochre Issues in the Brograve Catchment.* Broads Internal Drainage Board.

English Heritage, 2006. *Climate Change and the Historic Environment*. English Heritage.

English Nature, 2000. *Breydon Water Ramsar site (extended area).* English Nature.

English Nature and Environment Agency, 2003. *Winterton Coastal Habitat Management Plan (CHaMP)* English Nature and the Environment Agency.

English Nature, 2003. *Conservation of dynamic coasts; A framework for managing Natura 2000* English Nature, Peterborough.

Harding, M. and Smith, K. (2002) *Ochre in the Brograve Catchment – Causes and Cures.* Happisburgh-Winterton Internal Drainage Board.

Hopkins, J.J., Allison, H.M., Walmsley, C.A., Gaywood, M. and Thurgate, G. 2007. *Conserving biodiversity in a changing climate; guidance on building capacity to adapt*. Defra, London.

Hickling, R., Boy, D.B., Hill, J.K., Fox, R. and Thomas, C.D. 2006. 'The distributions of a wide range of taxonomic groups are expanding polewards'. *Global Change Biology* 12, 450–455.

HPA, 2008. Health *effects of climate change in the UK 2008.* Department of Health, London.

Hulme, M., Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchell, T.D., Jones, R.G., Lowe, J., Murphy, J.M., Hassell, D., Boorman, P., McDonald, R. and Hill, S. 2002. Climate change scenarios for the United Kingdom: the UKCIP02 Scientific report, UKCIP, Oxford.

IPCC. 2001. *Summary for policymakers*. A report of Working Group I of the Intergovernmental Panel on Climate Change, IPCC. Geneva.

IPCC. 2007. Climate change 2007: The physical science basis – Summary for policymakers, IPCC, Geneva.

Jenkins, G.J., Parry, M.C. and Prior, M.J.O. 2007. *The climate of the United Kingdom and recent trends.* UKCIP, Oxford.

Land Use Consultants (LUC) and University of Sheffield, with University of East Anglia and University of Reading. 2006. *The Future Character and Function of England's Landscapes: Overview Report*. *A literature review and commentary on research projects investigating future scenarios for England*. Prepared for The Countryside Agency.

Natural England, 2007. *Happisburgh Cliffs SSSI Citation*. Available at http://www.english-nature.org.uk/citation/citation_photo/1001304.pdf.

Natural England, 2007. *Bramerton Pits SSSI Citation*. Available at http://www.english-nature.org.uk/citation/citation_photo/1000688.pdf.

Morrissey, T., Ashmore, M.R., Emberson, L.D., Cinderby, S., Buker, P. 2007. *The impacts of ozone on nature conservation*, JNCC Report 403.

OST. 2002. *Foresight Futures 2020: Revised scenarios and guidance*. Office of Science and Technology, London.

Parolo, G. and Rossi, G. 2007. 'Upward migration of vascular plants following a climate warming trend in the Alps'. *Basic and Applied Ecology* doi:10.1016/j.baae.2007.01.005.

POST, 2006. *Ecosystem Services*. Postnote 281. Parliamentary Office of Science and Technology, London.

Shennan, I. and Horton, B. 2002. Holocene land- and sea-level changes in Great Britain. *Journal of Quaternary Science* 17: 511-526.

Sparks, T., Crick, H. Woiwod, I. and Beebee,T. 2001. 'Climate change and phenology in the United Kingdom' in Green, R., Harley, M. Spalding, M. and Zockler, C. (eds) *Impacts of climate change on wildlife* RSPB, Sandy.

UKCIP, 2001. *Socio-economic scenarios for climate change impact assessment: A guide to their use in the UK* UKCIP, Oxford.

UKCIP, 2003. *Climate adaptation; Risk, uncertainty and decision-making* UKCIP Technical Report, UKCIP, Oxford.

UKCIP, 2007. *Updates to regional net sea-level change estimates for Great Britain.* Available at http://www.ukcip.org.uk/images/stories/Scenarios/UKCIP02extras/slr_estimates.pdf.

Walmsley, CA., Smithers, R.J., Berry, P.M., Harley, M., Stevenson, M.J. and Catchpole, R. 2007. *MONARCH – Modelling natural resource responses to climate change – a synthesis for biodiversity conservation.* UKCIP, Oxford.

Appendix 1 Background and project methodology

There is little doubt that climate change is a reality and that it will pervade all areas of life. While there are impacts that are no longer avoidable, there is still time to develop adaptation techniques to cope with a changing climate, and mitigation strategies to limit further damage in the 21st century.

The Earth's climate is dynamic; the planet alternates between periods of glacial (cold) and interglacial (warm) conditions as part of its natural cycle (IPCC, 2001). While this is often altered by such events as large volcanic eruptions, the cycle is consistent. For the past 10,000 years the Earth has been in an interglacial period, which has provided a comfortable 15°C average surface temperature for mankind. However, there is substantial evidence that the impact of human activities has caused, and will continue to cause, a steady but significant increase in this average surface temperature.

The Earth is kept warm by certain gases in its atmosphere; gases such as water vapour, carbon dioxide (CO_2) and methane absorb outgoing radiation and re-emit it back to the Earth's surface. This has been described as the 'greenhouse effect', without which the Earth's surface would be approximately 33°C colder. Since the industrial revolution, mankind has consistently been adding to the greenhouse gases already in the atmosphere. Through burning of fossil fuels and changes in land use, the volume of greenhouse gases has increased from 270 parts per million volume (ppmv) in pre-industrial times to 379 ppmv in 2005 (IPCC, 2007). This far exceeds the natural range of the past 650,000 years (180 to 300 ppmv) as determined by ice cores (IPCC, 2007). This has caused an intensification of the greenhouse effect and a gradual warming of the Earth.

Addressing the challenges associated with climate change requires a 'two-pronged' approach; mitigation to limit the magnitude and rate of change and adaptation to deal with the residual impacts and opportunities. However, irrespective of the success of mitigation efforts, there will still be some degree of unavoidable climate change due to historic emissions of greenhouse gases (GHGs). Responding to the impacts of climate change requires adaptation. With respect to climate change, adaptation is thought of as 'an adjustment in natural or human systems to actual or expected climatic stimuli (variability, extremes and changes) or their effects, which moderates harm or exploits beneficial opportunities' (UKCIP 2007; 4). Adaptation requires effective measures directed at enhancing our capacity to adapt and at minimising, adjusting to and taking advantage of the consequences of climatic change.

The purpose of Natural England is to conserve, enhance and manage the natural environment for the benefit of current and future generations. In doing so, Natural England works towards the delivery of four strategic outcomes:

- A healthy natural environment: England's natural environment will be conserved and enhanced.
- Enjoyment of the natural environment: more people enjoying, understanding and acting to improve, the natural environment, more often.
- Sustainable use of the natural environment: the use and management of the natural environment is more sustainable.
- A secure environmental future: decisions which collectively secure the future of the natural environment.

The delivery of all of the above strategic outcomes is likely to be affected by direct and indirect impacts of climate change. For example, biodiversity is likely to be directly affected by changes in temperature and precipitation but is also susceptible to indirect impacts of climate change on other functions e.g. agriculture, recreation and flood risk. There will be threats and opportunities that arise as a result of the impacts of climate change and forward planning is required to ensure these are recognised and the appropriate action taken. It is therefore important for Natural England to identify how climate change will affect their functions and what action is required to adapt to them.

This project has selected four pilot Character Areas for climate change impact and adaptation assessment. The four Character Areas have been selected to represent a range of habitats and landscapes that are likely to be impacted by climate change in different ways. The four Character Areas are:

- Shropshire Hills;
- Dorset Downs and Cranbourne Chase;
- Cumbria High Fells; and
- The Broads.

The purpose of the project is to create climate change response strategies for each of the selected Character Areas based on national and local expertise. In each Character Area an initial list of the more significant natural environmental assets has been complied; other valued assets may exist, but this exercise attempted to select some of the most important. Based on this list, Character Area specific impacts of climate change have been identified. Subsequently, Character Area specific response strategies have been complied that aim to practically adapt the habitats and landscapes in question, to the identified impacts of climate change.

Project methodology

The climate change responses are the result of dialogue between national experts and local staff within each Character Area. Figure A1 illustrates the method behind each Character Area report. Initially, national experts (in habitat types, species, landscape, access and recreation) were asked to fill in templates to identify the impacts of climate change on significant natural environmental assets.

The templates asked the National Experts to identify climate risks, as expressed by projected climate change. The nature of the effects generated by the risk were then identified; for example for arctic alpines the risk is an increase in temperature and the nature of the effect is that species are forced to higher altitude or north facing sites. The extent of the effect, both in terms of geographical variation and magnitude of change was then identified. The projected impacts column identified the biophysical impact of the risk on the asset in question, so for arctic alpines the impact is that species move upwards or are lost. Following identification of impacts, the national experts were asked to suggest practical action that could be taken to adapt to climate change. Any key assumptions made in the impact assessment or useful references are listed in the final column. Table A1.1 shows a worked example of the process for arctic alpine flora.

Table A1.1 Worked example of national expert template

Valued asset	Risk	Nature of effects	Extent of effects	Projected impacts	Proposed responses	Key assumptions
Arctic alpine plants	Increasing temperature	Forces them to higher altitude/north facing slopes	Amount of temp increase from bioclimatic data	Retreat to higher altitude or loss	Improve condition of existing habitat to maintain as long as possible	

These master templates were then sent to the regional offices containing each of the chosen Character Areas. Regional staff were then asked to collate the assets pertinent to the Character Area in question and construct a Character Area specific version of the template. At this point regional staff reviewed the information provided by the national experts and updated it to reflect the specificities of their Character Area. One Character Area held an internal workshop to complete this part of the process.

Once a draft Character Area template had been assembled, national experts and regional staff met at an internal workshop to discuss and refine them further. The output of the internal workshops were annotated Character Area templates to reflect discussion held and a second template detailing practical response strategies for adapting to climate change. In addition, cross cutting issues such as landscape and ecosystem services were discussed at the workshops

The outputs form the Character Area internal workshops formed the basis of the climate change response reports. Around these templates, a narrative has been written which captures discussions held during and after the internal workshops. Following the production of the draft Character Area reports small external workshops of local technical experts were held. The purpose of these engagements was to strengthen the draft reports and gather further evidence. Finally these inputs were incorporated into the reports and the text finalised.

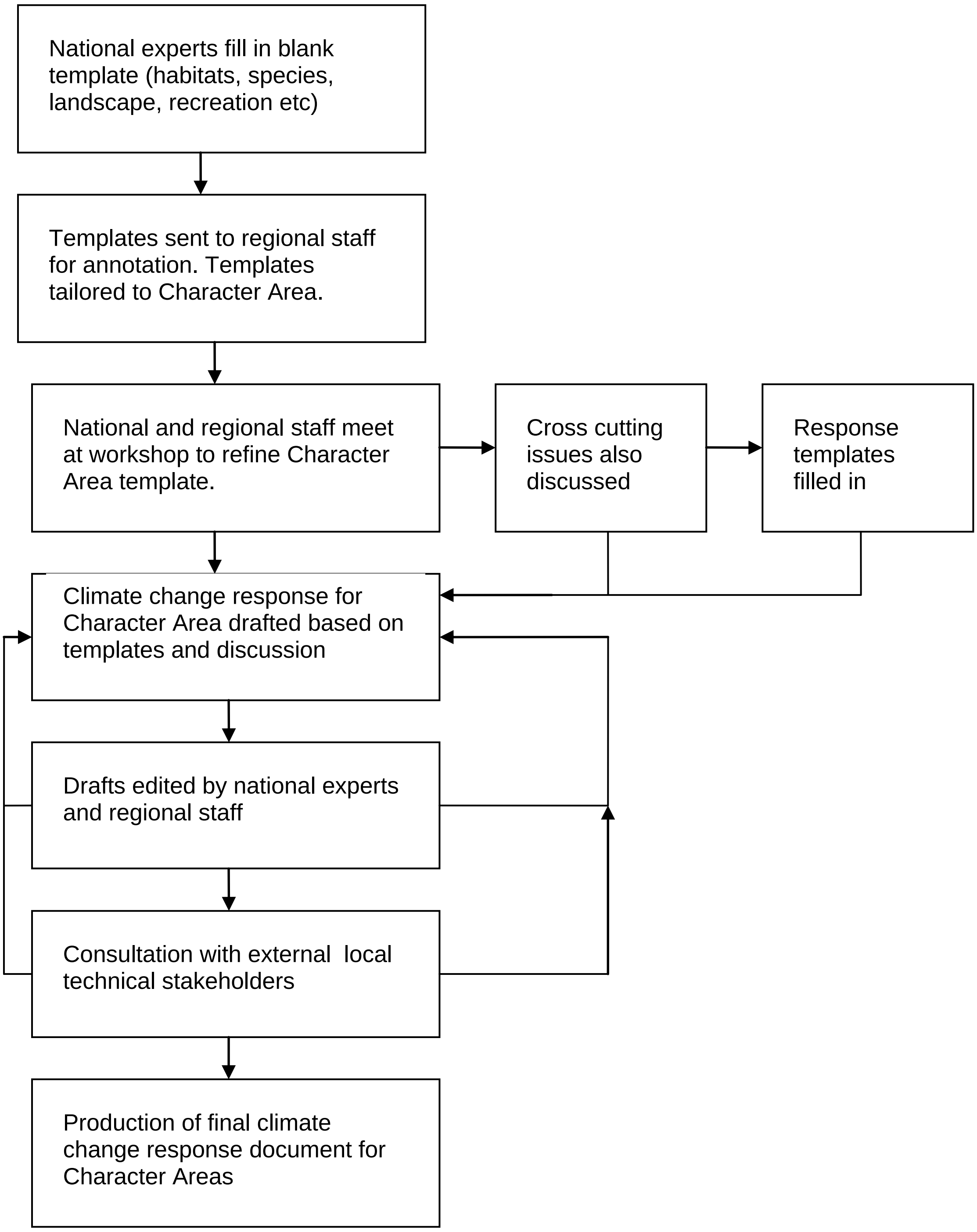


Figure A1.1 Flowchart showing project methodology

Appendix 2 Note on Indirect Climate Change and Socio-Economic Impacts

Socio-economic scenarios

Climate change will not be the only pressure on natural environments in the future. Other impacts will be felt through socio-economic change. Berkhout *et al*. (1999) identify five dimensions of socio-economic change:

- Demography and settlement patterns.
- The composition and rate of economic growth.
- The rate and direction of technological change.
- The nature of governance.
- Social and political values.

Given the deep level of uncertainty, traditional forecasting techniques are inappropriate. Instead, *scenarios* of socio-economic change are developed. Scenarios can be defined as:

> 'plausible, challenging and relevant sets of stories about how the future might unfold. They are generally developed to help decision-makers understand the wide range of possible futures, confront uncertainties and understand how decisions made now may play out in the future' (UNEP 2005)

Scenarios attempt to capture the dimensions of change described above; however, the last two dimensions are somewhat less tangible than the first three. The nature of governance concerns the degree to which governance is at a global or local scale. Governance can be international and strongly integrated or local and highly autonomous. Social and political values refer to the degree of individualism and consumerism that prevails, as opposed to communism and conservation. A continuum exists between the two extremes of each dimension and these can be used to form a matrix in which potential future socio-economic scenarios sit (see Figure A2.1). Other dimensions of change are then applied within this framework.

A number of socio-economic scenario sets have been constructed by a number of organisations for a range of purposes. Figure A2.1 includes socio-economic scenarios constructed by UKCIP (2001), for use alongside climate change impact and adaptation assessments, and the scenarios from the Millennium Ecosystem Assessment (MEA) (UNEP 2005). Both scenario sets consider the impacts on biodiversity, which are summarised in Table A2.1.

Table A2.1 Socio-economic scenarios related to biodiversity

Global Orchestration • Conservation sites maintained and slowly expanded but designed for access • Large-scale farming, GM crops • Urban sprawl and demand for 'managed landscapes'	**Techno-Garden** • High priority to protection • Pressures from growing demand • Low input farming and sustainable landscape management • Tight planning controls • Control of industrial pollution
Order-from-Strength • Policy not strong enough to restrict development pressures	**Adaptive-Mosaic** • Strenuous efforts to preserve wildlife • Access demands

• Little public concern about biodiversity • Intensified farming, larger farms • Environmental pollution	• Extensive and more diverse agricultural • Development controls

Adapted from UKCIP, 2001, with scenarios names from UNEP, 2005. Indirect socio-economic impacts i.e. socio-economic impacts on other sectors but with implications for biodiversity are shown *in italics*.

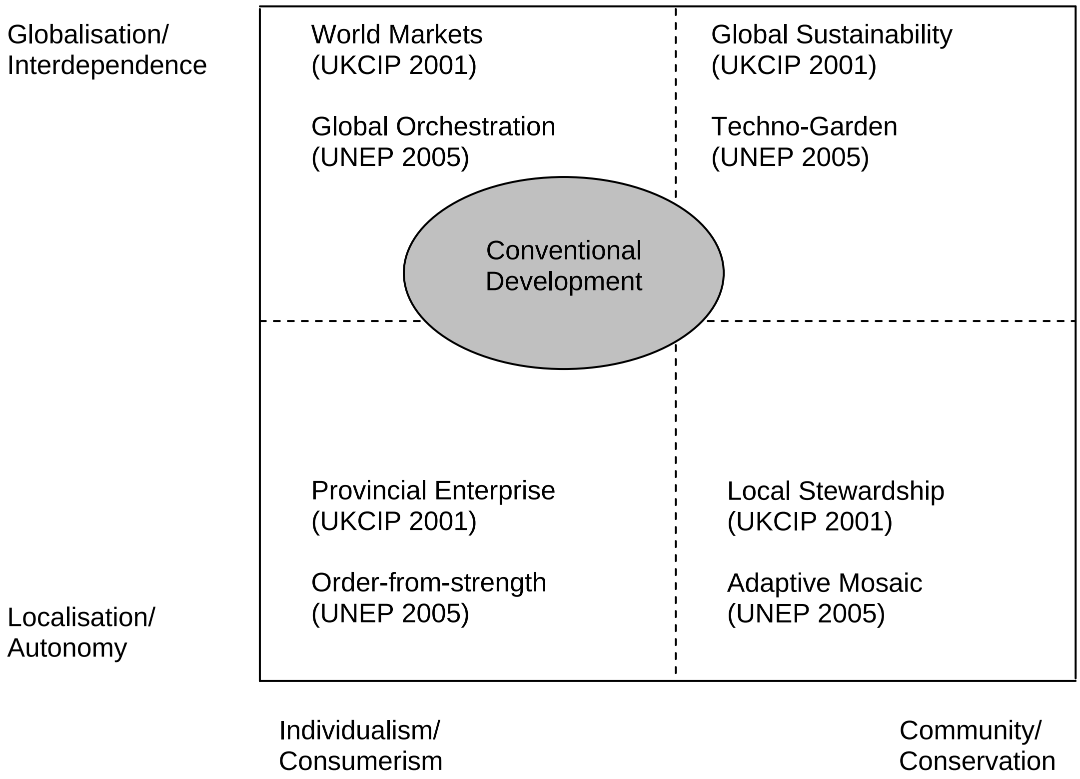
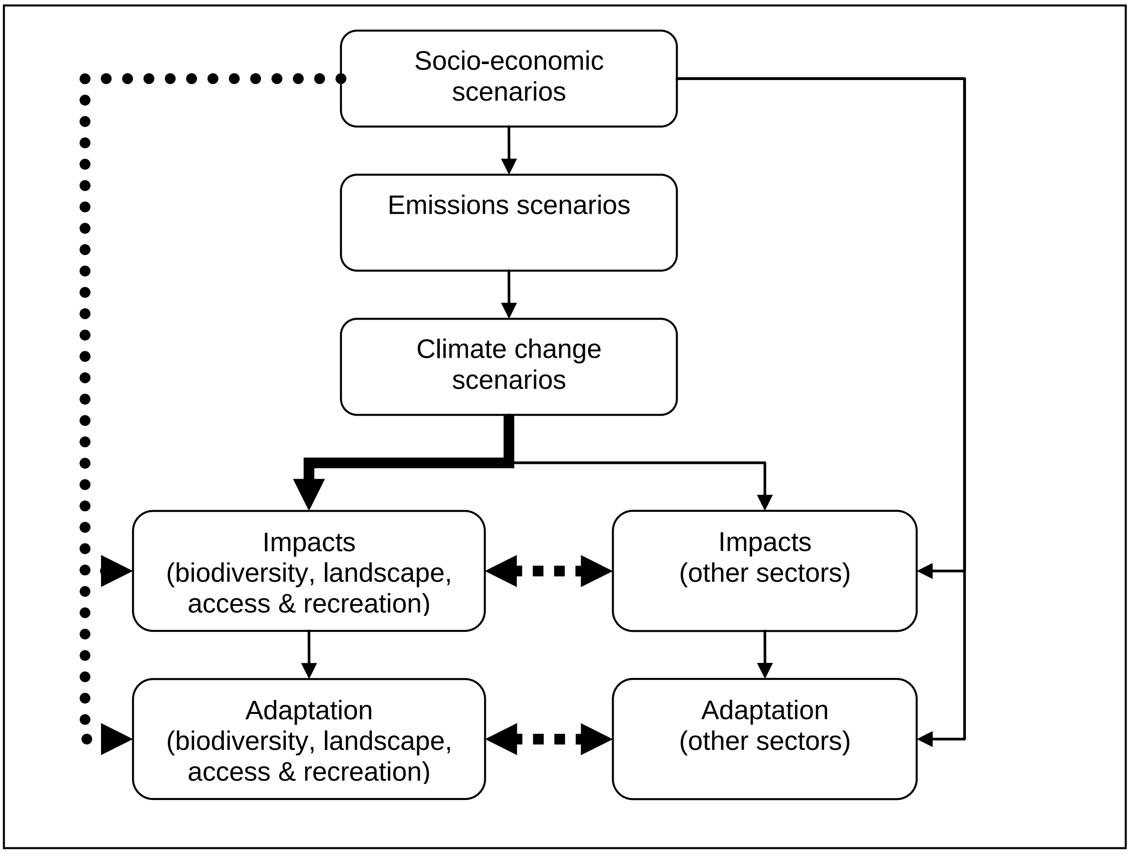


Figure A2.1 Socio-economic scenarios

Socio economic scenarios in climate change impact and adaptation assessment

We are increasingly used to working with climate change scenarios (such as those produced by UKCIP) to identify the direct and indirect impacts of climate change on assets of interest. These scenarios are informed by emissions scenarios (e.g. IPCC 2000) which are in turn driven by socio-economic scenarios (see Figure A3.2). Therefore the socio-economic scenarios not only directly and indirectly affect significant natural environmental assets of interest to Natural England; they also condition the climate change scenarios and resulting impacts. For this reason, socio-economic and climate change scenarios are often linked e.g. World Markets with High Emissions, although alternative 'cross-over' scenarios can be employed.



Thick solid line = direct climate change impact on biodiversity etc; dashed line = indirect climate change and socio-economic impact on biodiversity etc; dotted line = socio-economic impact on biodiversity etc.

Figure A2.2 Role of socio-economic scenarios in climate change impact and adaptation assessment

Significance of socio-economic scenarios for the Character Area project

Climate change will directly affect valued assets in the Character Areas. The significance of the impacts of climate change will be mediated by the socio-economic scenario that prevails at the time; changes in attitudes and behaviour towards the natural environment and conservation will alter the nature of the impacts. For example, the priority attached to dealing with species loss will be dependent on what we perceive as 'valuable' in the natural environment.

In addition to direct impacts, climate change will also have an indirect impact through interaction of assets with other sectors. For example, many Character Areas are heavily influenced by agriculture. Changes in agriculture could be driven by climate change, such as crop switching to more drought tolerant plants or increasing intensification due to the failure of harvests in other parts of the world. These would be classified as indirect impacts of climate change on the Character Area. These indirect impacts will also be mediated by the prevailing socio-economic scenario at the time.

However, shifts in agriculture may occur regardless of climate change e.g. driven by fluctuations in crop prices or shifts in consumer demand for certain products. Such changes would be classified as socio-economic impacts. These changes, whether climate induced or not, would significantly impact on the Character Areas.

Table A2.2 provides examples of direct, indirect and socio-economic impacts.

Table A2.2 Examples of direct, in-direct and socio-economic impacts

Type of impact	Examples
Direct climate change impact	• Increased stress due to drought • Phenological changes • Carbon dioxide fertilisation effect
In-direct climate change impact	• Increased visitor numbers in Character Area (due to an increase in temperature) • Reduction in water available for habitats (due to an increase in potable water demand)
Socio-economic impact	• Increase in invertebrate and bird species due to a shift towards organic farming • Development pressure in Character Area due to population increase

In reality direct, in-direct and socio-economic impacts are closely related. The Character Area project focuses on the direct biophysical impacts of climate change on the significant natural environmental assets of the Character Area (and is noting the downstream policy impacts where they arise). Where significant indirect impacts have been identified (such as those related to agricultural change in the face of climate change) these have been included and classified as indirect.

Table A2.3 considers a selection of in-direct impacts of climate change that may affect the natural environment.

Table A2.3 Indirect impacts of climate change on significant natural environmental assets

Sector primarily impacted	Impact of climate change	How it might affect natural environment
Agriculture, horticulture and forestry	Crop switching to more drought resistant crops Re-intensification due to failure of harvests elsewhere Increase in irrigation requirements	Landscape change Landscape change, reduced access to the natural environment, increase in diffuse pollution, species compositional change, reduction of network size Reduction in water available for habitats
Flood management	Reduction in condition of existing defences and risk of subsidence Increased risk of breach and overtopping of defences	Potential for habitat creation Increased risk of inundation of sites
Water resources	Increase in demand, reduction in supply Increased storage requirements	Reduction in water available for habitats Potential for habitat creation
Buildings	Risk of subsidence Risk of overheating	Increase in running costs of buildings

Sector primarily impacted	Impact of climate change	How it might affect natural environment
Transport	Subsidence Damage to infrastructure	Reduced access to natural environment
Retail	Increased opportunity for outdoor retail	Increase in recreation potential
Leisure and tourism	Increase in visitor numbers	Increase in recreation opportunity Risk of overcrowding leading to loss of visitor experience, damage to footpaths, increased pressure on resources and infrastructure
Health	Increase in heat related illnesses	Reduced outdoor recreation in summer

The Character Area project has not adopted a formal scenario based approach, nor does it provide an integrated assessment as these are highly complex. Instead, it is assumed that conventional development (mainly World Markets with aspects of other scenarios) will prevail.

Table A2.4 provides some examples of socio-economic impacts, which could affect the species, habitats, landscapes and recreational function of the Character Areas. This is based on knowledge of socio-economic changes, informed by current trends and drivers (e.g. the Water Framework Directive; European and UK Climate Change Programmes) and the futures literature (e.g. Evans and others 2004; LUC and others 2006; OST, 2002; UKCIP, 2001).

Table A2.4 Socio-economic changes with potential to affect natural environment

Sector	Socio economic change	How it might affect natural environment
Agriculture, horticulture and forestry	Increase in demand for organic produce Changes in payments and subsidies	Increase in invertebrate and bird species Reduction in diffuse pollution Improve countryside stewardship Reduce monoculture
Flood management	Preference for ‘soft defences’ e.g. managed realignment Changes in flood defence budget (decrease) Changes in flood defences (increase)	Increase in inter-tidal and floodplain habitat creation potential Greater risk of inundation of valued assets – positive for some and negative for others Reduced risk of inundation of valued assets – positive for some and negative for others
Water resources	Increase in water metering Introduction of variable tariffs Increased pressure on water resources in growth areas due to population increase	Potential increase in water available for habitats as potable consumption reduces Potential decrease in water available for habitats in growth areas

Sector	Socio economic change	How it might affect natural environment
Energy	Increase in oil price resulting in switch to renewables Switch to nuclear energy	Negative landscape impact of wind turbines Risk of diffuse pollution, landscape impact
Buildings	Increase in new build rates to meet demand from population growth – urban expansion Demand for waterside locations	Pressure on land Diffuse pollution
Transport	Demand for new infrastructure – roads, railways, runways etc to meet growing demand	Habitat fragmentation, landscape impact. Positive impact on access to countryside
Manufacturing and industry	Shift of heavy industry to other parts of the world	Reduction in diffuse pollution, increase in sites available for habitat restoration and creation
Financial services	Demand for ethical investment increases	Increased financial support
Retail	Movement of retail out-of-town Increase in ethical shopping	Pressure on land Increased awareness of value of natural environment
Leisure and tourism	Increased demand for extreme sports Increased demand for eco-tourism	Increase in visitor numbers and demand for facilities and infrastructure Reverse some of the negative effects of previous tourism
Health	Increase in obesity	Increased potential to market the countryside as part of a healthy lifestyle
Defence	Terrorism	Heightened security measure required

Mitigation

Addressing the challenges associated with climate change requires a ‘two-pronged’ approach: mitigation to limit the magnitude and rate of change and adaptation to deal with the residual impacts and opportunities. In climate change literature, mitigation refers specifically to the reduction in greenhouse gas emissions (UKCIP 2003). Mitigation is often driven by policy e.g. the UK Climate Change Programme. In addition to direct and in-direct impacts of climate change, assets can be impacted by mitigation policy. Table A2.5 illustrates some potential impacts of mitigation policy on the significant natural environmental assets. Note that other mitigation actions e.g. individual, corporate or market-based may also affect assets, although they are likely to be of a similar type.

Table A2.5 Mitigation policy impacts on Natural England

Sector	Mitigation policy	How it might affect Natural England objectives
Agriculture, horticulture and forestry	Increase in biofuel production Increase carbon store in soils and biomass	Landscape change, increase in monoculture Habitat creation potential
Flood management	Support use of non-carbon intensive forms of flood defence	Habitat creation potential
Water resources	Reduce energy demand of water treatment	Diffuse pollution
Energy	Shift to renewable energy or nuclear	Landscape impact of wind turbines / new power stations
Transport	Renewable transport fuel Increase in public transport	Landscape change, increase in monoculture Shift in how people access recreational facilities, new infrastructure required
Manufacturing and industry	Burning of biofuels and Combined Heat and Power	Landscape change, increase in monoculture. Opportunity to capitalise on demand for waste organic products (e.g. wood chippings generated through reserve management)

References

Berkhout, F., Hertin, J., Lorenzoni, I. Jordan, A., Turner, K., O'Riordan, T., Cobb, D., Ledoux, L., Tinch, R., Hulme, M. Palutikof, J. and Skea, J. 1999. *Non-Climate Futures Study: Socio-Economic Futures Scenarios for Climate Impact Assessment*. Final Report. SPRU, Brighton, Sussex, UK.

Evans, E., Ashley, R., Hall, J., Penning-Rowsell, E.C., Saul, A., Sayers, P., Thorne, C.R. and Watkinson, A. 2004. *Foresight. Future Flooding. Scientific Summary: Volume I - Future risks and their drivers*. Office of Science and Technology, London.

IPCC. 2000. *Special Report on Emission Scenarios. Summary for Policymakers*. A Special Report of Working Group III of the Intergovernmental Panel on Climate Change.

Land Use Consultants (LUC) and University of Sheffield, with University of East Anglia and University of Reading. 2006. *The Future Character and Function of England's Landscapes: Overview Report*. *A literature review and commentary on research projects investigating future scenarios for England*. Prepared for The Countryside Agency.

OST. 2002. *Foresight Futures 2020: Revised scenarios and guidance*. Office of Science and Technology, London.

UKCIP, 2003. *Climate adaptation; Risk, uncertainty and decision-making*. UKCIP Technical Report. UK Climate Impacts Programme, Oxford.

UKCIP. 2001. *Socio-economic scenarios for climate change impact assessment: a guide to their use in the UK Climate Impacts Programme*. UK Climate Impacts Programme, Oxford.

UNEP. 2005. *Millenium Ecosystem Assessment.*

Appendix 3 Tables accompanying narrative

Table A3.1: Impacts on the significant natural environmental assets of the Broads Character Area

Key
Indirect impacts are highlighted in italics
<u>Policy impacts are underlined</u>

Reference	Assets	Risk i.e. projected climate change	List and nature of the effects generated by the projected climate change	Extent of the effects	Projected impacts	Key assumptions
1	**Wet woodland.** Designated site feature on Broads SAC and Ramsar and component SSSIs Includes Annex 1 habitats Priority BAP habitat	Reduced summer rainfall Summer temperature increase Higher intensity rainfall events	*Lower water tables in some sites affected by increased abstraction* Drought Sea-level rise	Stands of wet woodland present within drained flood compartments Stands of wet woodland present on naturally functioning floodplain.	1a. Changes in ground flora communities 1b. Loss of condition of designated sites. 1c. Failure to achieve Favourable Conservation Status on Annex 1 habitats 1d. Failure to meet HAP targets 1e. Potential opportunities for habitat creation on flood storage land 1f. Loss of coastal wet woods through marine incursion 1g. Stands of wet woodland present within drained flood compartments more likely to be affected by summer drying. 1h. Stands of wet woodland present on naturally functioning floodplain more likely to be affected by increasing water levels as a consequence of higher intensity rainfall, increased tidal locking and sea-level rise.	Key factors are water level regime, availability of water and water quality for the maintenance of this habitat.
2	**Wetland habitats** Some communities are designated site feature on Broads	Higher temperatures Increased storminess	Higher water / soil temperatures Higher evapo-transpiration rates	Widespread and dependent on the response to flood management at the coast and within the	2a. Increased potential for invasive plants 2b. Increased reproductive capacity and over winter survival of insect etc disease vectors	The potential impact of climate change on all wetland ecosystems is confounded by complex interactions between temperature increases and changes to hydrological regimes and

	SAC and component SSSIs Includes Annex 1 habitats Also support birds recognised under the Broadland SPA and Ramsar site. Priority BAP habitat	Higher intensity rainfall	Increased primary productivity Longer growing season Sea level rise / saline incursion	broads floodplain itself. Increases in water level linked to increased storminess and higher intensity rainfall are likely to affect wetlands throughout The Broads Character Area in some years. While in other years summer droughts will impact these wetland habitats.	2c. Lower dissolved oxygen 2d. Increased toxicity of pollutants 2e. Lower water levels - decreased flushing/longer retention times in periodically inundated habitats (interaction with water quality pressures) 2f. Loss of connection with other freshwater habitat (rivers, ditch systems) 2g. Unpredictable inundation of floodplain fen and floodplain grazing marsh. Increased silt loading when inundation occurs 2h. Increased run-off, sediment and nutrient delivery – eutrophication exacerbated 2i. Increased water level fluctuation and erosion of marginal features 2j. Loss of freshwater flora and fauna either periodically or permanently	chemical processes. Direct impacts are not fully understood but impacts will be mediated by land use and management of water resources. This is dependent on socio-economic factors: agricultural land use change; demand for water and sewerage; flood management; social responses to increased vector borne disease risks. A better understanding is developing of the hydrological requirements of wetlands and the range of tolerable water levels can be given for a number of habitats. Yet to develop a similar approach for nutrient regimes. The establishment of 8 landscape scale wetland complexes as part of the revised Wetland Habitat Action Plan embraces the idea of larger areas conferring resilience and robustness to impacts including climate change and cuts across all wetland habitat types. Joint wetland Vision work aims to contribute to this.
3	**Reedbed** Supports species recognised as part of the	Higher temperatures (summer & winter) Increased	Long term coastal re-alignment and flooding Higher water	The reedbeds at the coast may be vulnerable to possible future coastal realignment.	3a. Marine incursion within the Upper Thurne would eliminate the extensive reedbeds of this area. 3b. Increase saline intrusion into the	

	Broadland SPA and Ramsar site and component SSSIs Includes Annex 1 habitats Priority BAP habitat	storminess Lower summer rainfall Higher intensity rainfall Sea level rise	temperatures Higher evapo-transpiration rates Saline intrusion		Broadland rivers will result in the conversion of brackish reedbed to upper saltmarsh habitat along the lower reaches 3c. May be some impact on summer water levels as a result of lower summer rainfall, drainage and abstraction.	
4	**Fens – Floodplain and valley fens** Some communities are designated site feature on Broads SAC and component SSSIs Includes Annex 1 habitats Also support birds recognised under the Broadland SPA and Ramsar site. Priority BAP habitat	Higher temperatures (summer & winter) Increased winter rainfall Increase in extreme rainfall events. Increased storminess Higher intensity rainfall Sea level rise/saline incursion	Sea level rise Higher water temperatures Higher evapo-transpiration rates	The majority of the fen in The Broads CA is of the floodplain type. Groundwater dependant fens are of a very limited extent in The Broads Character Area, being limited to the upper river valleys and smaller tributaries. Smallburgh Fen SAC/SPA/Ramsar & SSSI is a notable example of this habitat type.	4a. Marine incursion within the Upper Thurne would eliminate the extensive floodplain fen of this area. 4b. Fen situated on naturally functioning floodplain more likely to be affected by increasing water levels as a consequence of higher intensity rainfall, increased tidal locking and sea-level rise. Summer droughts are also increasingly possible. 4c. Fen habitats within flood compartments and those ground water fed sites are more likely to suffer the effects of summer drought 4d. Increased risk of polluted run-off with increased winter rainfall and extreme rainfall events. 4e. Boreal species may be lost from southerly sites. 4f. Unpredictable inundation of floodplain fen. Increased silt loading when inundation occurs.	Fens encompass a very wide range of habitat types, all of which will respond to climate change in different ways. Floodplain fens face same risks as reedbed, particularly loss to sea level rise, e.g. Broads fens. Impact on ground-water dependent fens may vary depending on aquifer type and degree of winter recharge. Recent modelling suggests fens fed by chalk aquifers (e.g. North Norfolk valley fens, Cothill Fen) may be particularly vulnerable. However, impacts will be mediated by ground water abstraction rates – limiting these further may reduce risk.
5	**Reedbed Birds**	Reduced summer	Spring and summer	The reedbeds of the	5a. Mild winter weather promotes sward	Sea-levels rise, birds do not use

	Bittern, Marsh Harrier, Bearded Tit, Cetti's and Reed Warblers, ducks, Grebes, egrets. Many species recognized under the Broadland SPA/Ramsar and SSSIs	rainfall Increase in extreme events Milder winters	drought Sea-level rise Spring and summer flooding Long term coastal re-alignment and flooding	Upper Thurne catchment may be vulnerable to future coastal realignment. Effects of drought, flooding and saline incursion are likely to be experienced throughout the floodplain.	growth 5b. Fens and reedbeds dry - food become unavailable, predation on eggs and young facilitated by drying, breeding assemblage declines/lost (ducks, reedbed birds) 5c. Freshwater reedbeds become saline and tidal – nest sites lost, food (fish and amphibians) lost, characteristic species (e.g. Bittern) locally extirpated, with national consequences 5d. Increased summer storm intensity coupled with drainage of much of the floodplain puts floodwaters into freshwater wetlands rapidly causing nests to flood, chicks to drown and eventual loss of ground nesting birds 5e. SSSIs and SPAs move to unfavourable condition (if not already unfavourable) 5f. Failure to meet BAP targets as loss of existing resource may outstrip pace of creation 5g. Lack of productivity, declining populations of key wetland species	saline habitat Current bias in avian biodiversity interest heavily skewed to small number of exceptionally important and also exceptionally vulnerable sites (such as the broads) – these disproportionately important in terms of proportion of population held there or in terms of driving overall UK productivity Summer flooding already happening at Minsmere, Nene Washes, Ouse Washes
6	**Purple moor-grass and rush pastures** Priority HAP type synonymous with: NVC types M22 - M26	Drier summers Wetter, warmer winters	More severe summer drought episodes Longer growing seasons	Purple moor-grass and rush pastures are present on peaty margins of drained flood compartments and within functioning floodplain fen areas.	6a. Loss of/declining condition in parts of the SSSI/SAC series. 6b. Continuing unfavorable conservation status for Annex 1 habitat. 6c. Difficulty in meeting lowland dry acid	There is a real paucity of any habitat specific evidence of likely impacts of climate change for this priority grassland type. Responses of these Molinia and Juncus dominated communities to climate change will be related to the

	M24 Recognized within the Broads SAC/Broadland Ramsar M22 SSSI feature on a number of sites			M24 is vulnerable to reductions in watertable, flooding and dereliction. M22 is likely to be vulnerable given its South and Eastern distribution, though no specific studies have focused on this community type.	<u>grassland HAP/BAP targets</u> 6d. For relatively wet examples of M24, a reduction in water table will result in the loss of some mire species and 'M13 characteristic' species. 6e. Loss of key boreal- montane species in stands of M26 may cause shifts in community composition. 6f. Loss of wetland interest and increased representation by 'dryland' species. 6g. Prolonged inundation in winter may shift towards true fen or swamp communities. 6h. Potential declines and losses of Boreal montane (Pinguicula vulgaris) and Boreal temperate (Potentilla erecta, Equisetum palustre Molinia caerulea) biogeographic elements of fen meadows, particularly in M26 6i. Potential increase in spring biomass and decline in summer biomass 6j. Decline in abundance and diversity of associated mosses, particularly sphagnum component 6k. Derelict stands will be prone to scrub invasion and woodland succession and a concomitant loss of species typical of fen meadows/rush pastures e.g. Cirsium dissectum	life-history attributes of the dominant species.
7	**Broads** Two types - naturally nutrient	Increase temperatures Increased	Higher water temperatures Higher evapo-	Extent will depend heavily on interaction with other pressures in particular nutrient	7a. Increased primary productivity (exacerbating eutrophication symptoms) 7b. Greater frequency and duration of (toxic)	The potential impact of climate change on lake ecosystems is confounded by interactions between temperature increases and changes

	rich waters that support pondweed; oligotrophic waters with Chara formations. Both are recognized within the Broads SAC/Broadland Ramsar. A number of sites are recognized as SSSI features. Sub-set of mesotrophic lakes are also a priority HAP	storminess and higher intensity rainfall Sea level rise/saline incursion	transpiration rates Lower water availability	enrichment (eutrophication). Some impacts e.g. those resulting from saline incursion will be primarily limited to shallow lakes in coastal situations and connected to the middle and lower river reaches.	algal blooms 7c. Longer growing season (increased potential for invasive plants) 7d. Recruitment possible for introduced fish species e.g. carp 7e. Lower dissolved oxygen 7f. Exposure of littoral (shore) communities 7g. Decreased flushing/longer retention times (interaction with water quality pressures) 7h. Loss of fish spawning habitat 7i. Loss of connection with other freshwater habitat (rivers, ditch systems) 7j. Increased run-off, sediment and nutrient delivery 7k. Increased suspended sediment. 7l. Increased water level fluctuation and erosion of marginal features 7m. Loss of freshwater flora and fauna 7n. ‘Forward switch’ to turbid algal dominated state 7o. Flips between saline, brackish and	to hydrological regimes. The strong socio-economic dimension to freshwater management makes it difficult to consider climate change impacts in isolation from sectors such as the water industry, inland navigation, fisheries and flood management. Microcosm studies have suggested that nutrient loads and the presence of predatory fish are more important drivers of shallow lake function than warming. Shallow lakes can exist in at least two alternative stable states – clear water plant dominated (high biodiversity and aesthetic value) and turbid algal dominated (low biodiversity value, ‘potentially’ low recreational value). At low nutrient levels the probability of a clear state is very high; at very high nutrient levels the probability of a turbid state is high. At intermediate (but anthropogenically enhanced) nutrient levels either state is possible but a turbid state can result from ‘switches’ by other factors. Typical switches include changes to fish community, introduction of bottom feeding fish, loss of aquatic plants. Many climate change impacts could

					freshwater states 7p. Ochre (iron precipitation) production	act as forward switches. A key threshold is likely to be around 50ug/l total phosphorus – above this shallow lakes are likely to be very susceptible to forward switches. Note sea-level rise needs to be viewed as a progressive change rather than sudden switch. Even where a major breach occurs it is likely that there will be a gradual transition back to freshwater or brackish conditions with high runoff events. A key impact will be gradual increases in the frequency and duration of saline events.
8	**River** Some sections lie within SSSIs	Increased winter rainfall Reduction in summer rainfall Increase in extreme events	Sea level rise and tide locking Reduced summer water levels at some times due to summer drought	Throughout The Broads CA river system.	8a. Loss of/declining condition of designated features in some SSSI and local sites as a result of engineering schemes related to flood and erosion management. 8b. Increased erosion and sedimentation leading to increased need to dredge to maintain both waterway access and water quality /biodiversity targets. 8c. Channel system changes. 8d. Channel abandonment or reduction in maintained depth (and burial); vegetation growth 8e. Increased risk of invasive aliens and need for increased channel maintenance *8f. Development related to renewable energy*	

					(hydroelectricity).	
9	**Coastal and floodplain grazing marsh** Supports species recognised as part of the Broadland SPA and Ramsar site and component SSSIs Also supports freshwater ditch habitat recognised under the Broads SAC Includes Annex 1 habitats Priority BAP habitat	Higher temperatures (summer & winter) Increased storminess and higher intensity rainfall Sea level rise	Higher water temperatures Higher evapo-transpiration rates Lower water availability Saline incursion		9a. Likely to suffer from summer rainfall deficit. 9b. Unpredictable inundation of floodplain grazing marsh. 9c. Increased silt loading when inundation occurs. 9d. Loss of breeding habitat for wetland bird species. *9e. Landowners threatened with summer drought will introduce river water into their marshes to maintain wet fences*. 9f. Poor water quality within the river will adversely impact the ditch communities but could be used to wet marshes.	
10	**Birds coastal and floodplain grazing marsh** Lapwing, Redshank, Snipe, Black-tailed Godwit, ducks, Geese and Swans, Grebes, Egrets,	Spring and summer drought Sea-level rise Spring and summer flooding	Increased summer storm intensity Surge/tide locking	Throughout much of The Broads CA area	10a. Mild winter weather promotes sward growth 10b. Wet grasslands dry out – food becomes unavailable, predation on eggs and young facilitated by drying, breeding assemblage declines/lost (Lapwing, Redshank, Snipe, ducks) 10c. Increased frequency of inundation of grazing marsh through overtopping of embankments putting floodwaters into freshwater wetlands, rapidly causing nests to	Sea-levels rise, birds do not use saline habitat Summer flooding already happening at Minsmere, Nene Washes, Ouse Washes

					flood, chicks to drown and eventual loss of ground nesting birds 10d. Many winter grazers (Wigeon, Swans, and Geese) appear in internationally important numbers to graze short swards. Tall swards largely unsuitable, decline in site condition as birds move 'elsewhere' 10e. SSSIs and SPAs move to unfavourable condition (if not already unfavourable) 10f. Failure to meet BAP targets as loss of existing resource may outstrip pace of creation 10g. Repeated lack of productivity, declining populations of key wetland species	
11	**Ditch systems and Ponds** Freshwater ditches and ponds <1ha in The Broads Character Area support naturally nutrient rich waters that support pondweeds, while others support oligotrophic waters with Chara	Increase temperatures Increased storminess and higher intensity rainfall Sea level rise/saline incursion	Higher water temperatures Longer growing season Higher evapo-transpiration rates Increased frequency and duration of droughts events Increased storminess and	Extent will depend heavily on interaction with other pressures in particular standards of flood management, abstraction, climate and nutrient enrichment. Marshes within the Upper Thurne will become more saline as a repercussion of sea level rise and subterranean intrusion.	11a. Increased primary productivity (exacerbating eutrophication symptoms) 11b. Greater frequency and duration of (toxic) algal blooms 11c. Increased potential for invasive plants 11d. Recruitment possible for introduced fish species e.g. carp 11e. Lower dissolved oxygen 11f. Increased toxicity of substances 11g. Exposure of littoral (shore) communities	Major impacts are associated with drying out and increased susceptibility to nutrient enrichment. (Interestingly in some ponds drying out could mediate nutrient enrichment/succession processes by allowing oxidation of accumulated organic material). Ditch networks and ponds both behind embankments and within the natural floodplain likely to be increasingly impacted by peak flow events – introduction of nutrients, salt, sediment and new species. While habitats fairly resilient

	formations. Both of these habitat types are recognized within the Broads SAC/Broadland Ramsar. A number of sites are recognized as SSSI features.		higher intensity rainfall Sea level rise/saline incursion (particularly coastal grazing marsh ditches)		and drying out of habitat 11h. Decreased flushing/longer retention times (interaction with water quality pressures) 11i. Loss of fish spawning habitat 11j. Loss of connection with other freshwater habitat (rivers, ditch systems) 11k. Increased run-off, sediment and nutrient delivery 11m. Loss of freshwater flora and fauna 11n. Loss of brackish transition zone 11o. 'Forward switch' to turbid algal dominated state 11p. Flips between saline, brackish and freshwater states 11q. Ochre (iron precipitation) production *11r. Landowners threatened with summer drought will introduce river water into their marshes to maintain wet fences.*	increasing frequency of events will cause an impact.
12	**Lowland dry acid grassland**. Priority HAP type (NVC U1, U3, U4)	Drier summers Increased temperatures	Longer growing seasons Summer drought	Across the range of the habitat but effects may be more pronounced in SE & eastern England.	12a. Summer drought may favour annual species over perennials leading to community change 12b. Milder winters may reduce frost heaving	

	Designated SSSI features. The Broads Character Area supports stands of U1. These are very limited in extent the best example being East Ruston Common SSSI in the Upper Ant Valley	Wetter winters			characteristic of U1 vegetation especially in eastern England 12c. Community composition may shift to favour southern temperate and Mediterranean continental elements in flora. 12d. Oceanic/sub-oceanic species may decline - examples include Ornithopus perpusillus, Aira praecox and Leontodon saxatilis. 12e. Certain acid grassland species are predicted to lose climate space by 2080 namely Koeleria macrantha (U1) and Erica cinerea (U3). 12f. Erodium cicutarium (U1) may lose climate space from some part of its current distribution but simultaneously expand its range northwards. Silene otites (U1) currently with a restricted easterly distribution is predicted to gain climate space. Brecks species currently. 12g. Less summer forage available for livestock grazing 12h. SSSI condition may become "unfavourable". 12i. Difficulty in meeting lowland dry acid grassland HAP/BAP targets	
13	**Species rich**	Wetter winters	Longer growing	Across the range of the	13a. Wetter winters may lead to higher	The component plant species of the

	grasslands (NVC MG5, MG8) Priority HAP type Designated SSSI features. MG5 occurs in all 4 pilot CAs MG8 probably occurs in all 4 Character Areas	Drier summers Increased temperatures	seasons Higher water tables/increasing frequency and duration of flooding	community but drought effects may be more pronounced in SE England	frequency/duration of high soil water tables/flooding events 13b. Flooding could threaten the integrity of alluvial flood meadows as the component plants of the community are more prone to increasing wetness than to summer drought. 13c. SSSI condition will become "unfavourable". 13d. Difficulty in meeting lowland hay meadow HAP/BAP targets 13e. Temperature changes may cause certain species to flower/set seed earlier in season 13f. Increased spring temperatures (and legacy of wetter winters) may boost total biomass and favour competitive species 13g. Drier summers will favour stress tolerant (e.g. deep-rooted species) and ruderal species but retard competitors/stress-tolerant competitors. 13h. Phenology of characteristic lowland meadow plant species may change significantly in response to climatic prompts.	various lowland meadow types mostly belong to the southern temperate, widespread temperate and temperate biogeographical elements. This suggests that the three lowland meadow NVC types might be relatively resilient to climate change scenarios, especially those related to temperature.
14	**Lowland Heathland** Priority HAP type, Designated SSSI	Increase temperatures Decrease in summer rainfall	Summer drought		14a. Increased above ground biomass 14b. Increased herbivory damage. More heather beetle attacks. 14c. Less CO_2 allocated to soil. Positive	The main papers dealing with impacts of climate change (drought and warming) on heathlands in the UK refer to an upland site in Wales, but they are the best info that exists.

	features, Annex 1 types under Habitats Directive Dune heath present within the Winterton/ Horsey areas. Lowland heath present in some sites adjacent to the broads floodplain.				warming feedback as more CO_2 is released. 14d. Changes in soil chemistry. Possible impacts on soil fauna. Litter fall tended to decrease. Increased spring leaching of nitrate 14e. Acceleration of spring growth 14f. Loss of species depending on bare ground and open areas 14g. Changes in community composition – loss of Erica tetralix and increased Calluna vulgaris 14h. Decreased Calluna vulgaris flowering. Decreased seedbank of Calluna vulgaris. 14i. Lower plant replacement rate.	
15	**Birds of Lowland Heathland**	Increasing summer temperatures Increasingly mild winters		S, SW, SE and Central, possible North	15a. Increasing range and numbers 15b. Resident insectivores (Dartford Warbler) hit hard by cold winters: increasing mildness has allowed population on existing heaths to increase, new heaths to be colonised and for upland areas to north and west of recent range to be colonised	
16	**Coastal habitats**	Sea level rise		Sea levels around England could rise by 36 cm by 2050, however there will be variation around the coast due to local	16a. Habitat erosion likely to be exacerbated by sea level rise and increased storminess, particularly where coastal defence structures prevent landward movement of habitats, leading to 'coastal squeeze'.	Coastal habitats provide a 'front line' in exhibiting responses to climate change. There is a great understanding of how systems have responded in the past to environmental change/perturbation.

				conditions such as tides, winds, local currents and local subsidence with the most marked sea level rise in SE England Coasts such as Norfolk are still undergoing large-scale system retreat as a result of size in sea level since the last glaciation (has risen by 65m since then). Waves, tides, surges, wind, storm events, sediment availability and size, amount of isostatic change. Greatest increase in sea level rise will be in Thames estuary under UKCIP98 scenarios, extends to E Anglia & Kent	16b. Changes in coastal geomorphology 16c. The mix of coastal habitats at local sites in the UK will change in extent, location and species assemblages. 16d. Species assemblages will change, affecting bird and mammal food sources. BRANCH models show that mudflats, dunes, wetlands and freshwater ponds are the most vulnerable coastal habitats to climate change.	The relationship between coastal habitats and freshwater habitats is important and also covered by CHaMPs studies. There are limited long time series monitoring sites for coastal habitats- Need to build on available data by establishing long time-series coastal monitoring stations based on ECN approach. The 2004 Foresight report on Future Flooding provides a key source of references for the extent of change at the coast (and on rivers). Note: It covers coastal erosion as well as flooding.
17	**Saltmarsh and estuaries** Primarily located at Breydon Water SPA/Ramsar. Although saltmarsh is increasingly spreading higher	Increase storminess Increase in temperatures	Increase in wind and wave energy considered to be key impacts Storm surges	Extent likely to decline on the UK's south coast as sea-levels rise The morphology of estuaries is likely to alter substantially, particularly in the south-east of England.	17a. Loss of saltmarsh is of concern as it forms the base of estuarine food webs - particularly mudflats 17b. Changes in community composition due to increased submergence 17c. Impacts on internal creek patterns which could affect the rate of internal erosion and sediment transport within the saltmarsh.	As extent declines, quality of habitat also likely to decline.

	up the rivers lower reaches in response to ongoing increasing saline intrusion			At Breydon Water sediment levels are increasing as it is acting as a net sediment sink. So habitat may be more resilient in this situation.	17d. Changes to a sandier substrate due to more flushing of finer particles. Would affect bird food types and potentially vegetation types 17e. Because saltmarsh dissipates wave energy, its loss will increase the pressure on coastal defence structures.	
18	**Estuarine Birds** Knot, Redshank, Dunlin, Curlew, Turnstone, Purple Sandpiper, Grey and Golden Plover, Black-tailed and Bar-tailed Godwits Breydon Water is an SPA/Ramsar, commonly now supporting in excess of 100,000 birds	Mild UK and European winters		Throughout UK	18a. Much of the interest moves south and west from breeding grounds to overwinter in UK – as conditions become increasingly mild in eastern UK and in nearby continental Europe, fewer birds fly to winter in south and west 18b. Northward retreat impossible, huge scale breeding failure and catastrophic decline in global numbers 18c. East and north showing increase (This is reflected in the figures for Breydon Water)	Birds move from SW to NE
19	**Sand dunes** Much of this habitat within the CA lies within the Winterton-Horsey Dunes SAC/SSSI The SAC	Increase in storminess Increase in temperature Decrease in summer precipitation	Increased wind speed	Dunes are quite widespread along coast-different areas may have different responses. The dune frontage of this CA is fronted by a concrete seawall, in	19a. Dunes likely to decline on the UK's south coast as sea-levels rise. 19b. Sandy beaches are likely to suffer from increased erosion in response to an increase in the number and severity of storms 19c. Future changes in shoreline position and dune system area are likely to affect sand	

	recognizes embryonic shifting dune, dune slack, dune heath and white dune			some places this is buried within the dune. While the seawall is present the dune habitat behind it is fairly well protected, the embryonic shifting dunes are particularly vulnerable. This is currently dependant upon a beach recharge scheme that also protects the toe of the seawall.	stability, dune mobility and groundwater levels, which in turn will affect habitats 19d. Dunes may have less wind-blown sand if beach plains are smaller or wetter. If dunes get drier, they may lose surface vegetation 19e. Embryonic shifting dune will be lost if beach recharge scheme reduced or ceased.	
20	**Beach nesting birds** Little Terns are a designated feature of the Great Yarmouth North Denes SPA which also covers the Winterton Horsey Dunes complex. This is the largest Little Tern colony in the country	Increased summer storminess Increased temperature	Increasing sea temperatures Enhanced growth rates of alien plants species (e.g. mallows, nettles, hottentot figs)	Throughout coastal area	20a. Decline in numbers/desertion of sites 20b. Annual productivity failures, decline in breeding numbers 20c. Repeated productivity failures, decline in population 20d. Loss of nesting areas 20e. Nesting birds buried in sand, foam or flooded out or washed from sea-cliffs 20f. Change in fish distributions away from current nesting colonies, so decline in food and potential decline in fish waste (and so seabird food) as fisheries move or fail 20g. As ecosystem structure shifts the numbers of generalist large predatory seabirds may increase and prey on smaller	

					seabirds	
21	**Maritime Cliff and slope** There is a very limited extent of this habitat within the Character Area. Happisburgh Cliffs SSSI	Increased winter rainfall Increased temperature	Increase in erosion rates	Would be limited to those stretches of coast with soft cliffs	21a. Cliff erosion and landslides, changes in extent of cliff-top habitat 21b. More rapid retreat of coastal soft cliffs- more toe erosion and more rainfall increasing groundwater levels. 21c. Reactivation of old landslide complexes 21d. Impacts of climate change on cliff recession rates will vary-not well studied. May affect water balance and hence seepages for invertebrates, warmer temperatures could promote invasive plant species, changes in slope morphology could affect quality of habitat for invertebrates	
22	**Geological interest - Inland outcrops** Very limited with CA restricted to Bramerton Pits SSSI Broome Heath Pit SSSI	Increase in temperature Increase in winter rainfall	Increased rates of weathering	Effects similar nationally although most outcrops of this type are in upland areas.	22a. Increased rain and temperature will result in increased vegetation growth 22b. Loss of/declining condition of designated features in some SSSI and local sites as a result of features becoming obscured. 22c. Slumping / mass movement obscuring features 22d. Vegetation growth obscuring features.	
23	**Access around Urban Fringe** Character Area abuts three urban	Increased temperatures Decreased rainfall in summer	Hotter weather may encourage people to take holidays in the UK/ become more	Urban fringe Suburban areas	23a. Problems particularly significant at holiday times on transport infrastructure. 23b. Increase need for local greenspaces for recreation	While Norwich has a country park (Whitlingham), Great Yarmouth and Lowestoft do not have one – Promote new gateway country parks at both locations (eg. BROADLINK Runham Broad)

	areas – Norwich, Great Yarmouth and Lowestoft		active		23c. Cost of travel increase 23d. Flooding & weather damage	
24	**Access to Countryside**	Increased temperatures Decreased rainfall in summer	Hotter weather may encourage people to take holidays in the UK/ become more active Drought Fires	Attractive rural areas Rivers/lakes/reservoirs Marshes-broads Heathland	24a. Problems particularly significant at holiday times on transport infrastructure. 24b. Drought causing negative impact on water recreation. Blue green algae, reduced water levels. 24c. Potential reintroduction in vector borne diseases e.g. malaria in salt mash districts. Tick borne diseases. Unlikely that most dangerous forms will establish 24d. Cost of travel increase 24e. Countryside seen as dangerous. Reduction in demand for outdoor recreation. 24f. Small areas of potential damage & areas not available for recreation. 24g. Possible reduction in travel to more remote areas as cost increases.	Assumes visitor numbers will increase with rising temperatures.
25	**Access in protected areas**	Increased temperatures Decreased rainfall in summer	Hotter weather may encourage people to take holidays in the UK/ become more active Drought. Fires	More significant impact likely on charismatic sites e.g. the Broads CA and Norfolk Coast AONB. Rivers/ and broads	25a. Problems particularly significant at holiday times on transport infrastructure. 25b. Drought causing negative impact on water recreation 25c. Flood embankments breached either by floodwaters or deliberately as part of	Impacts on staithes and moorings

				Heathland Much of the footpath access in The Broads Character Area is restricted to flood embankments.	floodplain management. 25d. Reduced access to resources. Reduced water quality – Blue Green algae 25e. Small areas of potential damage & areas not available for recreation. 25f. Reduction in length of footpath available or footpath sustained through bridges – unsustainable and costly.	
26	**Outdoor Recreation:** Effects of a wide range of sports and recreation activities.	Extreme weather conditions Dry spells Heavy rain	Increased erosion rate Fire	Particularly marked in fragile habitats but impact potential anywhere	26a. Huge variety of potentially damaging effects 26b. Increased erosion caused by recreation use in these conditions & opportunity for accidents (fire etc) 26c. Loss of vegetation 26d. Damage to footpaths	Review of the Relationship between Sport, Recreation and Nature Conservation. English Nature 2006 Unpublished England Leisure Visit Survey 2005

Table A3.2: Responses to climate change impacts in the Broads Character Area

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
Freshwater	8d 11g	Increase ability of catchments to retain rainfall (particularly within the floodplain) and reduce artificially enhanced surface run-off	High	Immediate	Medium	Very effective for a number of freshwater assets. Can be delivered through agri-environment scheme and planning system	Natural England Government (regulatory role) Environment Agency Land use planners	Reliance on voluntary action – need regulation catchment scale action required
	11j 7i	Restoration of natural physical form of river valleys and function of river channels and floodplains – setting back of flood embankments Wetland creation to moderate extreme water levels	High	Immediate	Medium	Effective	Broadland Environmental Services Limited Environment Agency Broads Authority Land use planners Highways authorities	Lack of apparent flexibility in the delivery of flood management options in the Broads Lack of funding packages that would make such options attractive to landowners. Public understanding Pressure on land.
	7d 7m 8a 8e 11c 11d 11	Reflect potential for changes in species composition, particularly with regards to natural invasives, in conservation objectives and condition assessment.	High	Immediate	Low	Will need to be flexible and requires monitoring	Natural England	EU – Habitats Regulations

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
	m 11n							
	7j 7k 8b 11k	Catchment sensitive farming to reduce sediment loads	High	Immediate	Potentially high - polluter pays	Very effective if other pressures are reduced. Could be delivered through agri-environment schemes	Natural England Environment Agency Defra Farmers	Economics
	9c 11k	Establish adaptive management of the navigation through the depth of dredge	High	Immediate	Low		Broads Authority Natural England	
	3b 4a 5c 7o 7p 11p 11q	Re-wetting of soil to reduce ochre, acidity and saline inputs Block coastal drains to reduce sea water inputs	High	Immediate	Low /Medium	Would address ochre problem and have multiple benefits for wetland habitats. Reduce saline inputs.	Broads IDB Natural England Broads Authority Environment Agency	Delivering catchment-wide land use change. Economics. Public opinion Landowner consent
Wetland habitats	1e	Increased water retention within floodplain	High	Immediate	Low to high	Effective at responding to drying of wetlands. Will need monitoring to ensure long term effectiveness.	Broads IDB Environment Agency Broads Authority Natural England	Pressure on land Perceived flood risk Perceived and real impact on agricultural productivity
	1h 3c	Increase connectivity of wetland habitats with floodplain	High	Immediate	Medium	Effective	BESL Environment Agency Broads IDB Broads Authority	Lack of apparent flexibility in the delivery of flood management options in the

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
							and Land use planners Natural England	Broads Lack of funding packages that would make such options attractive to landowners. Public understanding Pressure on land. Economics
	4d	Reduce other sources of pressure on wetlands – over abstraction, pollution etc	High	Immediate	Medium	Necessary to increase resilience to climate change	Natural England Environment Agency Broads Authority Landowners and managers	Resources
	1a 1f 1g 2j 3a 3b 4a 4e	Freshwater habitat replacement	High	As soon as possible.	High	Effective at dealing with loss of freshwater habitat but may not be sustainable in the Broads – may need locations outside the Broads. Will be effective in the longer term but will require monitoring of climate change impacts.	Environment Agency Land use planners Natural England	Lack of suitable climate space Pressure on land Lag time – not visible Potential regrets Land owner attitudes Some habitats difficult or impossible to recreate
	1a 1b 1c	Reflect potential for changes in species composition in conservation objectives –	Medium	Before 2020	Low	Very effective but will require monitoring to ensure effectiveness	Natural England	EU – Habitat Regulations

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
	1d 2a 2j 5e 5f 6b 6c	improved representation of transition habitats				persists		
Lowland	12a 12b 12c 12d 12e 12f 13b	Maintain current habitat extent of moderate and high quality habitat	High	Immediate	Low	Will be partially effective but will need to be used on conjunction with other measures	Natural England Landowners and managers Broads Authority	
	12g 13e	Ensure existing sites are managed according to best practice guidelines	High	Immediate	Medium	Will be partially effective but will need to be used on conjunction with other measures	Natural England Broads Authority Landowners and managers	
	12a 12b 12c 12d 12e 12f 13e 13f 13g	Restoration of semi-improved grasslands and recreation on improved grassland/arable land	Medium	Before 2020	High	Will be partially effective but will need to be used on conjunction with other measures	Natural England Landowners and managers	Lack of suitable climate space Pressure on land Lag time – not visible Land owner attitudes
	12g	Vary the timing and duration	Medium	Before	Low	Will assist in adapting to	Natural England	Agricultural

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
	13e 13h 14a 14e	of grazing		2020		seasonal changes in habitat	Landowners and managers	economics
	12h 12i 13c 13d 15a	Modify conservation objectives to reflect shifts in community composition	Medium	Before 2020	Low	Very effective but will require monitoring to ensure effectiveness persists	Natural England	EU – Habitat Regulations
Coastal habitats	16a 16b	Review strategy for the coast as part of the Shoreline Management Plan process and the Environment Agency's Eccles to Winterton Strategy Review , ensuring policy is sustainable and adaptive in the face of climate change.	High	Before 2013	High	Potentially effective, however this is dependant upon the outcome of the review.	Environment Agency Land use planners	Public perception Lack of social justice mechanism. Uncertainty about future technical solutions Loss of valued assets.
	17a 17b 17c 17d 17e	Ensure estuary in favorable condition – reduce pressures other than climate change	High	Immediate	Low	Necessary to increase resilience to climate change – this will be achieved in part through the Review of Consents process	Natural England Environment Agency RSPB Local Authorities	
	17a 17b	As part of Broads Flood Alleviation Project, retreat flood embankments – increase area of rond habitat that supports saltmarsh	High	Immediate	High	Effective at increasing saltmarsh/intertidal habitats and has multiple benefits for other habitat and flood defence	BESL Environment Agency Natural England Broads Authority	Lack of funding packages that would make such options attractive to landowners.

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
		species where it does not result in increased saline intrusion.					Landowners and managers	Public understanding Pressure on land. Economics Landowners on rising ground not wanting water so close to them.
	19a 19c 19d	Reduce abstraction/drainage from dunes Drain blocking adjacent to the coast	High	Immediate	Low	Will sustain wetland dune slacks prone to drought	Broads IDB Natural England Environment Agency	Possible conflict with agricultural management
	21a 21b 21c 21d	Reduce non-natural run-off (e.g. from roads and buildings) on cliff tops	High	Immediate	Low	Will stabilise cliffs	Natural England Environment Agency Planning authorities	
Access and recreation	23a 24a 25a 26a	Model increase in visitor numbers and identify areas most at risk of damage	High	Immediate	Low	Will make implementation of management more effective	Broads Authority Tourist Boards Local Authorities Natural England	
	26b 26c 26d	Dispersal – promote other rights of way / attractions	High	Immediate	Low	Will require monitoring of visitor numbers and route usage. Effectiveness will depend on promotion and education.	Broads Authority Local Authorities Local Access Forum Highways authorities Natural England	Public perception of honeypot sites
	23d	Potential temporary closure	Medium	Ongoing	Low	Effectiveness will depend	Broads Authority	

Asset	Impact Ref	Response strategy	Priority	Timing	Cost	Extent to which impact dealt with by response	Responsibility	Barriers
	24f 25e 26b 26d	of footpaths				on promotion and education.	Local Authority Local Access Forum Environment Agency Highways authorities Natural England	
	23a 24a 25a 26a	Education of visitors through advertising and interpretive signing	High	Immediate	Medium	Will enhance effectiveness of other measures	Broads Authority Natural England Tourist Boards	
	23c 24d	Increase public transport provision throughout the Character Area	Medium	Immediate	High	Uncertain – depends on condition of infrastructure. Will require monitoring of user numbers.	Public transport providers	High cost

Table A3.3 Impacts on ecosystem service and possible responses

Category	Ecosystem Service	Impact of Climate Change	Response	Key assumptions
Provisioning services	Water resources	Lower summer flows - less water available for agricultural abstraction, recreation and habitats Increased overland flow during high intensity events – less groundwater recharge	Catchment management – improving permeability of surfaces through planting, water retention, sustainable urban drainage systems (SUDS) etc Demand management Switch to more drought resistant plants On farm water storage	Increases in efficiency could limit problem of low water availability in summer
	Farming	Changes to livestock / crop viability New pests and diseases affects crops and livestock Summer drought – higher agricultural water demand	Crop / livestock switching Improvements in water management – on farm storage, reduced surface run-off, increase infiltration rates Be aware of new pests and diseases	
Cultural services	Recreation	More opportunities – increased visitor numbers Risk of increase in congestion, footpath erosion, trampling Decrease in water availability and quality Loss of beaches	Improve recreational infrastructure where appropriate Identify vulnerable areas Educate visitors in how to minimise their impact	Assumes increase in visitor numbers with increase in temperature. Assumes conventional development prevails.
	Tourism	More visitors (esp. in shoulder months) Increased risk of congestion, footpath erosion, trampling	Improve recreational infrastructure where appropriate Identify vulnerable areas	Assumes increase in visitor numbers with increase in temperature. Assumes

Category	Ecosystem Service	Impact of Climate Change	Response	Key assumptions
		Greater pressure on resources – accommodation, transport infrastructure, water etc	Education Infrastructure vs. protection (debate needed)	conventional development prevails.
	Education	Increased demand for field studies	Change in curriculum	Assumes increase in visitor numbers with increase in temperature.
Supporting services	Soils	Quaternary deposits could be lost through erosion – impact on historical environment as they contain recent history	Improvement in soil and vegetation management Changes in agricultural practice Limiting visitor numbers in sensitive areas	
	Geology	Access issues if widespread habitat creation in response to climate change Change in fluvial processes Increase in coastal erosion – retreat of cliffs	Ensure access to geological features (may conflict with habitat extension and creation programmes)	
Regulating services	Flood protection	Increase in flood risk – greater winter rainfall, more overland flow, more storm events Reduction in coastal flood protection as beach is lost Impact on infrastructure – roads, rail, isolated communities etc	Catchment management – improving permeability of surfaces through planting, creation of wet woodland, SUDS etc Habitat creation opportunity from flood defence works – flood storage areas, managed realignment Temporary closure / diversion of rights of way	
	Water quality	Diffuse pollution – less dilution due to lower flows	Vegetation and soil management to achieve potable water improvements	

Category	Ecosystem Service	Impact of Climate Change	Response	Key assumptions
		Increase in nutrient loading due to increase in visitor numbers and potential agricultural re-intensification.	Vegetation buffer strips around fields Reduce nutrient input to water bodies	

Table A3.4 Socio-economic impacts and responses in the Broads Character Area

Sector	Socio economic changes	Impact on The Broads CA	Response	Key assumptions
Agriculture, horticulture and forestry	Increase in demand for organic produce Changes in payments and subsidies Increased concern for food security	Increase in invertebrate and bird species due to reduction in pesticides used Reduction in diffuse pollution Improved countryside stewardship Reduce monoculture Intensification of agriculture – loss of habitat	Extension of the habitat network through habitat creation on arable field margins	Assumes conventional development. Demand for organic and local produce would be highest under Local Markets. Concern for food security greatest under National Enterprise.
Water resources	Increase in water metering Introduction of variable tariffs Increased pressure on water resources due to population increase	Potential increase in water available for habitats as potable consumption reduces Potential decrease in water available for habitats	Wetland habitat creation and restoration Resist development in areas of water stress through the water resource and spatial planning system	Assumes water demand grows as population grows. Greater water efficiency may reduce per capita consumption.
Water quality	Increased pressure on water quality due to population increase	Potential decrease in water quality for habitats	Resist development in areas of water quality stress through the spatial planning system	Assumes water quality deteriorates as population grows.
Energy	Increase in oil price and concern over security of supply	Switch to renewable - negative landscape impact of wind turbines and biofuels	Resist inappropriate structures on the landscape through spatial planning system Strengthen landscape designations in The Broads Character Area	Increase in oil price and concern over security of supply could lead to increase in nuclear power rather than renewables
Buildings	Increase in new build rates to meet demand from population	Pressure on land	Resist development in sensitive areas through spatial planning	Assumes UK population will increase

Sector	Socio economic changes	Impact on The Broads CA	Response	Key assumptions
	growth and urban expansion		system Strengthen landscape designations in The Broads Character Area	
Transport	Demand for new infrastructure – roads, railways, runways etc. to meet growing demand	Habitat fragmentation, landscape impact. Positive impact on access to countryside	Resist development in sensitive areas through spatial planning system Improve public transport access to Character Area – reduce demand for travel	Assumes conventional development and limited use of public transport.
Leisure and tourism	Increased demand for outdoor activities – walking, cycling, gliding Increased demand for eco-tourism	Increase in visitor numbers and demand for facilities and infrastructure Reverse some of the negative effects of previous tourism	Visitor dispersal Education	
Health	Increase in obesity	Increased potential to market the countryside as part of a healthy lifestyle – increase number of people enjoying the countryside	Market the countryside as part of a healthy lifestyle	Assumes conventional development – lifestyles may change to be less sedentary