Natural England Commissioned Report NECR038

Climate change adaptation indicators for the natural environment

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Foreword

Natural England commission a range of reports from external contractors to provide evidence and advice to assist us in delivering our duties. The views in this report are those of the authors and do not necessarily represent those of Natural England.

Background

As organisations develop climate change adaptation actions we need to monitor and evaluate the effectiveness of these actions.

Over recent years the development of indicators has become a key part of policy development, ensuring that new policies and programmes are measurable and accountable.

Yet measuring adaptation poses a number of challenges given:

- the uncertainty of outcome;
- the imperfect state of knowledge; and
- the long time-scales involved.

Often we are trying to measure an avoided event (such as preventing loss of species from a nature reserve), against no fixed baseline (how would we know what species might have been lost had we not intervened?) at an uncertain point in the future or over a long time period. We also have to take account of the fact that climate change is one of a number of interacting causes of change (including air pollution and changing patterns of land management) and climate change adaptation is likely to be most effective when integrated into a broader range of objectives.

In this context, we commissioned this report to examine how an initial set of adaptation indicators for the natural environment might be developed.

The project aimed to identify a package of indicators to measure the level of adaptation planning and activity (process indicators) and the resilience of the natural environment (which can be regarded as a proxy outcome indicator). Whilst it may not be possible to define a desired adaptation outcome, there is a degree of consensus about characteristics that promote the resilience of the natural environment to climate change and this is a frequent objective of adaptation measures.

Natural England will use the findings to help inform our understanding of these issues and we are publishing the report so that other interested parties can use the same information. In reading the report, it is important to bear in mind that this is an evolving field and new opportunities may open up in the next few years, for example ongoing work on landscape monitoring may allow this to be more fully integrated in future.

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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**.

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Glossary of Terms

Adaptation – the process or outcome of a process that leads to a reduction in harm or risk of harm, or realisation of benefits, associated with climate variability and climate change (Willows and Connell 2003).

Adaptive capacity – the ability of a system to adjust to climate change, to moderate potential damages, to take advantage of opportunities or to cope with the consequences (Willows and Connell 2003).

Adaptive management – a lower risk approach to dealing with climate vulnerability through incremental introduction of adaptive measures or modifying existing management practices as part of an overall adaptation strategy. The approach involves introducing adaptive measures and monitoring and evaluating the results to ensure the measures remain effective as new evidence and other information becomes available. As a result of monitoring, the measures introduced may need to be reviewed again (continuous improvement process).

Climate vulnerability – defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change (Willows and Connell 2003). Vulnerability is a function of the character, magnitude and rate of climate change (often called the hazard) and variations to which a receptor is exposed, its sensitivity and its ability to adapt (adaptive capacity).

Indicator – a metric or value (preferably quantitative) used to demonstrate progress towards a target or objective (Defra 2005).

Resilience – the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change." (IPCC 2007).

Abbreviations

Abbreviation	Meaning
ANGS	Access to Natural Green Space
AONB	Area of Outstanding Natural Beauty
BAP	Biodiversity Action Plan
BTO	British trust for Ornithology
CAMS	Catchment Abstraction Management Strategy
DCLG	Department of Communities and Local Government
Defra	Department of Environment, Farming and Rural Affairs
EBG	England Biodiversity Group
ECN	Environmental Change Network
EEA	European Environment Agency
IPCC	Inter Governmental Panel on Climate Change
GHG	Greenhouse Gas
GIS	Geographic Information System
PSA	Public Service Agreement
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SEBI	Streamlining European Biodiversity Indictors
SNH	Scottish Natural Heritage
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPA	Special Protection Area
SSSI	Site of Special Scientific Interest
WFD	Water Framework Directive
WRMU	Water Resource Management Unit
WWT	Wildfowl and Wetlands Trust

1. Introduction

1.1 Background to project

Natural England is working to deliver a natural environment that is healthy, enjoyed by people and used sustainably now and in the future. However, the natural environment is changing, particularly as a consequence of human-induced land use and climate change. Some impacts of climate change are unavoidable as a result of historical emissions of greenhouse gases and the lag in the climate system. Adaptation to the impacts of climate change is thus essential.

At the time of writing this report Defra was investigating indicators of climate change adaptation and had asked for input from other government departments and agencies. This provided Natural England with an opportunity to propose the inclusion of a number of indicators of adaptation in the natural environment.

This project represents the first step in developing ideas for indicators of adaptation in the natural environment.

1.2 Background to indicators

To date, work in the field of climate change adaptation has resulted in many strategies for adaptation. However, there is relatively little work which has resulted in implementation of adaptation (Heller and Zavalet 2008). Some degree of climate change is inevitable so there is a need to start planning for future impacts now. As a result, there is a need to shift from work that purely aims to build adaptive capacity to work that also results in delivery of adaptation.

One of the barriers to the shift to adaptation action is uncertainty over what we are adapting to and how much adaptation is sufficient. However, the need for adaptation is clear and we should concentrate on delivering adaptation measures that are flexible enough to deal with uncertain future conditions.

Indicators are often used to measure contribution towards achieving a desired goal (performance measure). An indicator can be defined as "*a metric or value (preferably quantitative) used to demonstrate progress towards a target or objective*" (Defra 2005). Indicators serve four basic functions: simplification, quantification, standardisation and communication (EEA 2007) and should provide a link from monitoring and research to support evidence-based policy making.

There are two types of indicators: outcome indicators and process indicators. Outcome indicators measure the movement towards pre-defined, quantified targets or goals. Process indicators measure progress towards unquantifiable targets or goals with no defined end-point. Adaptation is best viewed as either as a process with no defined outcome or a process with stepped outcomes which will change over time. This suggests that adaptation is best measured by process indicators; however, there is a risk that process indicators alone will not measure delivery of adaptation but simply the process of planning adaptation (DCLG 2006).

Rather than solely measuring the process of adaptation, it may be possible to measure the desired outcome of adaptation. It is not possible to set a target for an amount of adaptation, as uncertainty over the future means that we do not know how much adaptation is enough. However, it is possible to qualitatively summarise the desired outcome of adaptation. The aim of adaptation in the natural environment can be summarised as 'to create a natural environment that is resilient to change' where resilience is defined as the "*ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-organisation, and the capacity to adapt to stress and change*" (IPCC 2007). A resilient natural environment has the capacity to adapt to a range of pressures and future climate and

other changes. Whilst there are still problems with measuring resilience there are at least widely agreed features which are believed to contribute to increased resilience, most of which can be measured.

1.3 Project aims

This project aims to identify a package of process and outcome indicators. In practice, this means identifying indicators which measure the process of planning for climate change and the characteristics of a resilient natural environment (as a proxy for measuring the outcome of adaptation).

The project aims to identify a package of resilience indicators based on literature review and discussion of existing indicator sets and measurements of the natural environment. Defra is keen to use existing indicators where possible. However, the project also aims to highlight areas where there are no suitable existing indicators. It is recognised that further work will be required to develop new indicators to fill these gaps.

The project aims to identify indicators for use at a strategic level rather than a local or regional scale. The method devised for identifying indicators should apply at other scales but further work is required to tailor the proposed indicators to a regional or local scale.

This project does not aim to measure the impacts of climate change in the natural environment, except in circumstances where a change in the impact indicates a change in resilience. There are a number of indicator sets which aim to measure the impacts of climate change on the natural environment e.g. Environmental Change Network (ECN) Climate Change Indicators[1]; Indicators of the impact of Climate Change on Migratory Species (Newson *et al*. 2008); and Indicators for Climate Change impacts on freshwater ecosystems (Euro-limpacs)[2].

1.4 Report structure

This report proposes a set of climate change adaptation indicators for Natural England and summarises the process by which they were reached. The report is arranged into the following chapters:

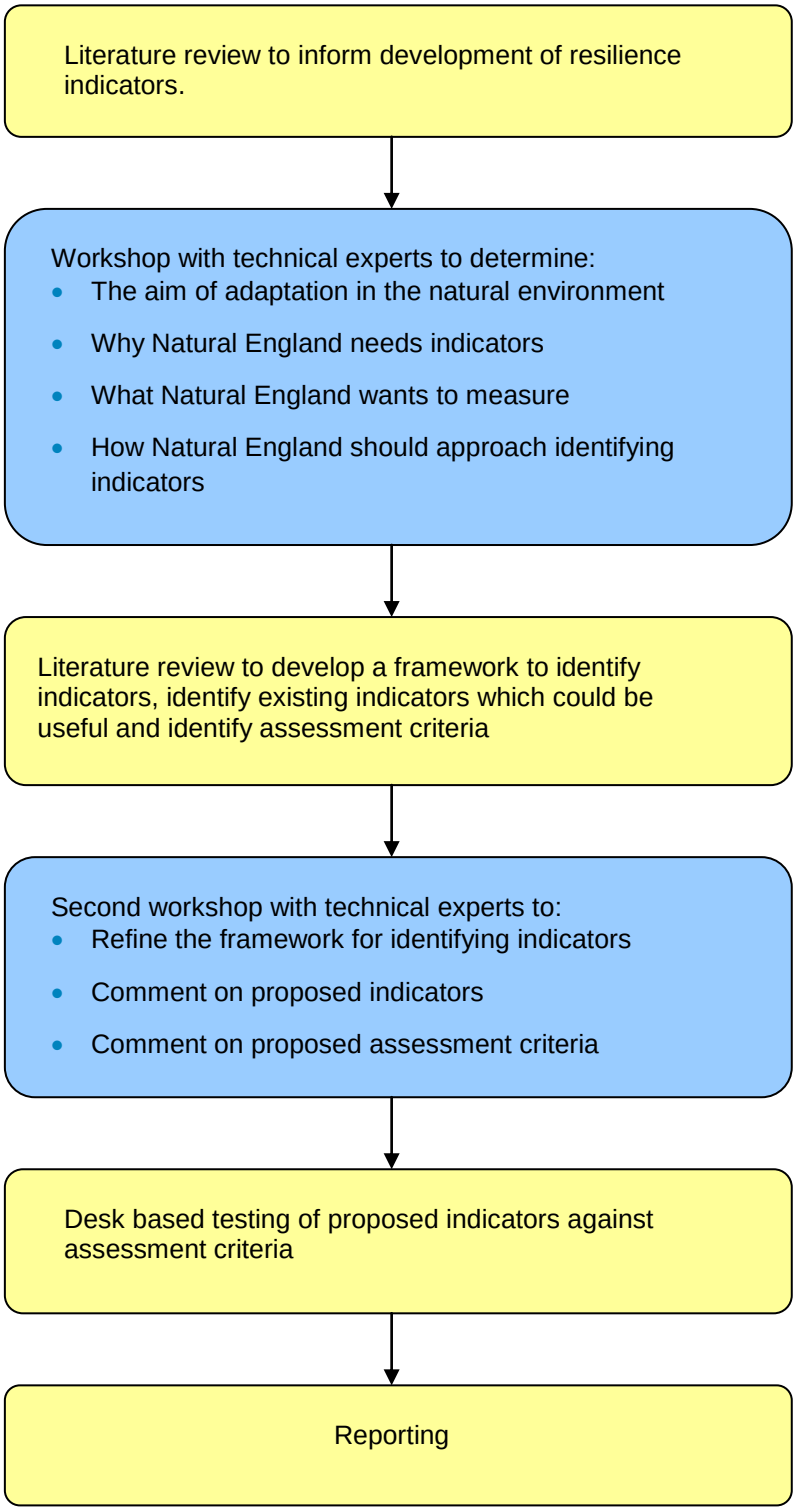
- Chapter 1 – Introduction;
- Chapter 2 - Methodology: summary of the method devised for identifying and testing potential resilience indicators;
- Chapter 3 – Proposed indicators: long list of potential resilience indicators;
- Chapter 4 – Testing indicators: evaluation of potential indicators against assessment criteria to ensure they are fit for purpose and selection of recommended indicators; and
- Chapter 5 – Further work: identification of gaps and further work necessary to develop the indicator set further.

[1] http://www.ecn.ac.uk/environmental_indicators.htm
[2] http://www.eurolimpacs.ucl.ac.uk/oldsite/userarea/database/wp7.1/

2. Methodology

The project has combined desk based research with workshops attended by technical experts from Natural England and partner organisations. Figure 2.1 illustrates the project methodology.

Figure 2.1 – Project methodology



2.1 Literature review - developing adaptation indicators

In order to provide further information and set the context for the project, a literature review of existing work involving natural environment indicators has been undertaken. A range of documents (including indicator sets, guidance on developing and using indicators and case studies of projects that use indicators) has been reviewed. This is complemented by the discussions at the first workshop. The main findings relevant to adaptation indicators are:

- Before it is possible to identify or select indicators, there needs to be a clearly defined outcome or target. However, as adaptation is a process rather than an outcome, when considering adaptation indicators it may not be possible (see Section 1.2), and therefore a set of principles may be more appropriate (Defra 2005);
- When identifying and selecting indicators, it is useful to look at existing indicators and assess whether they measure, or contribute to measuring, the desired outcome. Where established monitoring and reporting systems on sectoral issues related to adaptation are already in place, any indicator framework for adaptation should embrace them but avoid duplicating them (Defra 2005);
- Indicator identification and selection should be carried out in consultation with those who will be responsible for data collection and reporting, based on practical considerations of resources and existing processes (Defra 2005; Newson *et al*. 2008);
- When measuring adaptation to climate change the process-based approach may be seen as more appropriate because of high uncertainty and long timescales;
- However, there is a risk that process indicators alone will not measure delivery of adaptation but simply the process of planning adaptation (DCLG 2006);
- Use of climate change impact indicators to measure progress in adaptation may be problematic as attribution to adaptation actions, compared to changes in other drivers, is likely to be difficult; and
- The natural environment is complex; therefore, a suite of indicators is needed to give an adequate picture of adaptation (Rice and Richet 2005).

2.2 Framework for identifying indicators

Following the literature review, and in consultation with experts from Natural England and other organisations, a framework for identifying resilience indicators for the natural environment has been devised (see Figure 2.2).

The framework is underpinned by the set of principles for adapting the natural environment developed by the England Biodiversity Group (Smithers *et al*. 2008) (see Box 2.1). The principles have been used to devise the objective and identify the characteristics that make the natural environment resilient to climate change. The characteristics are then used to identify potential indicators of resilience.

Box 2.1 England Biodiversity Strategy Climate Change Adaptation Principles

(Smithers *et al*. 2008)

Take practical action now

- Conserve existing biodiversity;
- Conserve protected areas and all other high quality habitats;
- Reduce sources of harm not linked to climate;
- Use existing biodiversity legislation and international agreements.

Maintain and increase ecological resilience

- Conserve the range and variability of habitats and species;
- Maintain existing ecological networks;
- Create buffer zones around high quality habitats;
- Take prompt action to control spread of invasive species.

Accommodate change

- Understand change is inevitable;
- Make space for the natural development of rivers and coasts;
- Establish ecological networks through habitat restoration and creation;
- Aid gene flow;
- Consider the role of species translocation and ex-situ conservation;
- Develop the capacity of institutions and administrative arrangements to cope with change;
- Learn from experience and respond to changing conservation priorities.

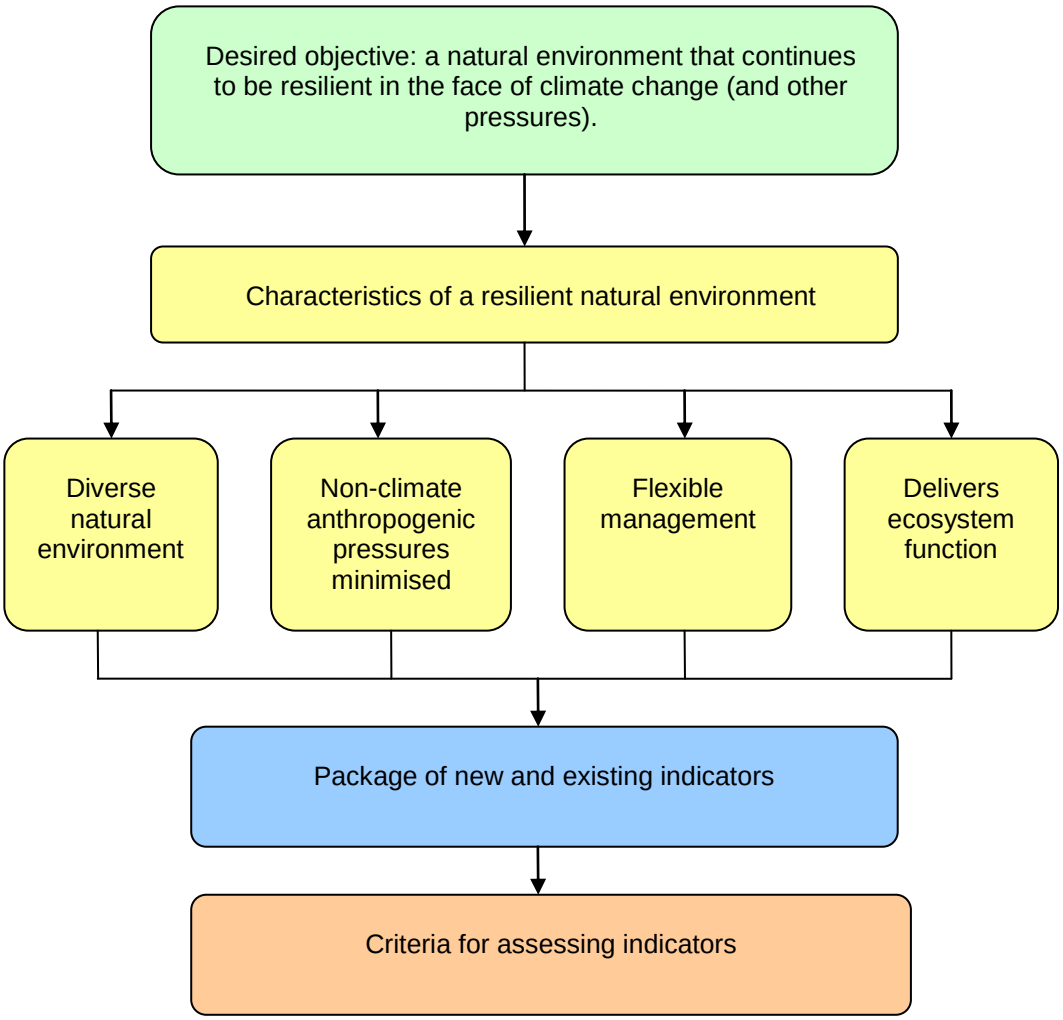
Integrate action across partners and sectors

- Integrate adaptation and mitigation measures;
- Integrate policy and practice across relevant economic sectors;
- Build and strengthen partnerships;
- Raise awareness of benefits of the natural environment to society.

Develop knowledge and plan strategically

- Undertake vulnerability assessments of biodiversity and associated ecosystem goods and services without delay;
- Undertake scenario planning and implementation of no regrets actions;
- Pilot and monitoring new approaches;
- Identify potential win-win solutions and ensuring cross-sectoral knowledge transfer;
- Monitor actual impacts and research likely future impacts.

Figure 2.2 – Framework for identifying indicators



2.2.1 Objective

Whilst it is difficult to identify an end-point for adaptation, it is easier to identify the aims of adaptation. The aims of adaptation used in this project are informed by the principles described in Section 2.2 and in consultation with a number of partner organisations at the first workshop. The aims of adaptation in the natural environment have therefore been identified as:

- To maintain and enhance adaptive capacity in the natural environment and allow for change;
- To maintain the value or function of the landscape or ecosystem rather than trying to maintain unchanged all the things in it;
- To deliver sustainable development and assist society in adapting to the impacts of climate change; and
- To maintain and enhance people's enjoyment of the natural environment.

These aims inform the development of an adaptation objective for the natural environment. **The objective Natural England is trying to achieve through adaptation actions is a natural environment which remains resilient in the face of climate change (and other pressures)**, where resilience is defined as "*the ability of a social or ecological system to absorb disturbances while retaining the same basic structure and ways of functioning, the capacity for self-*

organisation, and the capacity to adapt to stress and change." (IPCC 2007). This objective encompasses climate change but also other changes which could affect the natural environment, including changes in agriculture or population. This objective was agreed with the technical specialists from Natural England and partner organisations at the first workshop.

The aims and desired outcome of adaptation to climate change for the natural environment do not differ from Natural England's wider aim to maintain a healthy natural environment. What is different is the approach to maintaining a healthy natural environment i.e. increasing resilience to change rather than conserving what's there. The purpose of this project is to propose indicators which measure if this new approach is working.

2.2.2 Characteristics

In order to identify indicators to measure the objective it is necessary to determine what a resilient natural environment looks like. Through consultation with technical specialists at the second workshop and subsequent literature review, a set of characteristics of a resilient natural environment have been drawn up. The characteristics, informed by the adaptation principles, are:

- **A natural environment which is diverse**: a high level of structural diversity within the environment (e.g. habitat, vegetation, landscape, and topography) reduces vulnerability to climate (and other change) as it increases adaptive capacity;
- **A natural environment where non-climate anthropogenic pressures are minimised**: there are many other anthropogenic pressures acting on the natural environment as well as climate change. Whilst the natural environment will never be entirely free from anthropogenic stressors (e.g. high nutrient levels, air pollution), the impacts of these stressors should be reduced to levels which do not impair the ability of the system to function. Anthropogenic pressures should therefore be minimised and maintained below critical thresholds where these are known;
- **A natural environment which is managed flexibly:** increasing flexibility in the natural environment is important for increasing resilience to the impacts of climate change and dealing with uncertainty. Adaptive management is a lower risk approach to dealing with climate vulnerability through planned change or modification of existing management practices. The approach involves making a change to an existing practice and monitoring the results to ensure the response is effective as new evidence becomes available. As a result of monitoring, the practice may need to be reviewed again. Adaptive management needs to be actively planned and many areas may need more diverse management arrangements to allow a varied structure to develop; and
- **A natural environment which can continue to deliver ecosystem services**: one of the aims of adaptation is to maintain the function of the natural environment. A resilient natural environment should be able to maintain its functions in the face of climate (and other) changes. One way of identifying potential indicators would be to measure the four ecosystem services (as defined by the Millennium Ecosystem Assessment (Environmental Audit Committee 2007));
    - 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; and
    - Cultural services: such as education, recreation, and aesthetic value.

2.2.3 Indicators

As discussed above (Section 1.2) it is not possible to measure adaptation of the natural environment directly as there is uncertainty over what we are adapting too and what constitutes successful adaptation. It is easier to measure features of the natural environment which make it resilient to change. Indicators should therefore measure how resilient the natural environment is to climate change by measuring the extent to which the characteristics identified above are present or are being achieved.

Many of the characteristics are already measured in some way by existing natural environment indicator sets. This is unsurprising given that, often, action needed to address the existing adaptation deficit is largely consistent with doing what the natural environment sector does already. As the principles demonstrate, good management of the natural environment is critical in delivering resilience. Resilience does not necessarily need to be seen as something new: in many cases improving resilience is synonymous with good management of the natural environment (see Section 2.2.1 and Smithers *et al*. 2008).

One of the lessons from the literature review is that existing indicators should be used where possible as good quality and long-term data and the means for collecting it are likely to be in place. The first stage in identifying indicators is thus a review of existing indicator sets to identify those which have the potential to measure the characteristics described above. However, there is a need to ensure that where existing indicators are used, they are fit for purpose and fulfil the evaluation criteria (see below).

Where there are no suitable existing indicators, there will be a need to suggest and evaluate new or modified ones. The proposed indicators should be guided by the adaptation aims and principles.

In the case of resilience indicators it is not possible to set quantified targets of how much is enough due to the uncertainty associated with the impacts of climate change and the response of the natural environment. The proposed indicators are therefore not accompanied by any targets. For each indicator, an indication of how to interpret change in the context of resilience is given i.e. whether an increase in the indicator represents an increase or decrease in resilience. These interpretations will need to be reviewed on a regular basis as the climate changes and uncertainty over what constitutes a resilient natural environment is reduced.

2.2.4 Evaluation criteria

It is important to test the indicators to ensure they are fit for purpose. The chosen indicators should demonstrate that they are contributing to, or are a key part of, increasing the resilience of the natural environment. In order to test the proposed list of indicators, a list of criteria is required. The evaluation criteria should ensure that the indicators fulfil the desired objective by measuring the resilience of the natural environment. Identification of the criteria is based on literature review and consideration of the EBG adaptation principles.

3. Proposed indicators

3.1 Review of existing indicators and data

The first step in identifying potential indicators of resilience is to review the many existing sets of indicators in use in the natural environment and assess whether they can be used to measure the characteristics of a resilient natural environment (see Appendix A, Table A1). In addition to formally defined indicator sets, there are many aspects of the natural environment that are measured and could be used as resilience indicators (see Appendix A, Table A2). The literature review has been carried out using a pro forma (see Appendix B). The main lessons that can be drawn from the review of existing indicators are:

- There are many indicators and measures of the natural environment that are already being used and that are capable of measuring characteristics of a resilient natural environment. Many of these measurements are undertaken (or have the potential to be undertaken) by Natural England and partner organisations;
- There are a significant number of existing indicators that measure diversity, anthropogenic pressures on the natural environment and ecosystem services (see Table 3.1);
- The diversity indicators generally measure biodiversity in terms of:
    - The status of designated sites against pre-defined conditions (e.g. 'favourable condition'); and
    - Population size of certain proxy species which indicate wider ecosystem health (e.g. farmland birds);
- Care needs to be taken when using existing indicators that measure the status of a site against a pre-defined condition (in the context of adaptation to climate change), as the desired condition may change over time. Care must also be taken to avoid the assumption that sites present now are the ones that should be kept; it is more important to determine (through the use of indicators) if they are being managed appropriately;
- Structural diversity is not well measured by existing indicators, although there may be scope to link with Natural England's vulnerability mapping project;
- The 'anthropogenic pressures' indicators generally measure;
    - Exposure to pollution (air and water);
    - Invasive species;
    - Pressure on water resources;
- Measures of native species may not always be appropriate in the context of climate change. It will not always be possible to maintain populations of native species as climate space changes and new colonists arrive. It may therefore be more useful to use newly arriving species as indicators;
- There are few indicators that measure landscape distinctiveness, diversity, or the contribution of landscape to ecosystem services. This is likely due to the qualitative nature of landscape which does not lend itself to quantification or measurement by an indicator;
- There are few existing indicators that measure 'flexible management' (see Table 3.1) and it is likely that new indicators will have to be developed to measure this characteristic;
- There are a number of existing indicators which measure ecosystem services although they are largely limited to measuring access to the natural environment. Whilst changes in access

to the countryside may be used as a measure of the impact of climate change it may be difficult to use it as an indicator of resilience. Increasing access to the countryside will not necessarily contribute to an increase in resilience; it could have the opposite effect. It is therefore difficult to see how an access indicator can be interpreted in terms of resilience; and

- Ecosystem services are often measured indirectly through indicators which measure anthropogenic pressures on the natural environment e.g. abstractions; water quality. There are few that directly measure the benefits provided to people by ecosystems.

3.2 Proposed indicators

A list of suggested indicators for Natural England has been compiled based on the literature review, consultation with technical experts and collation of similar indicators and measurements from Tables 3.1 and 3.2 (see Table 3.3). These will be taken forward for evaluation against the assessment criteria in Section 4.

The complexity of the natural environment makes it very difficult to devise a single indicator that represents resilience to the impacts of climate change. It is also difficult to identify indicators that measure all the characteristics of a resilient natural environment. Therefore, a package of indicators is required which together measure all the characteristics (Rice and Rochet 2005) (see Table 3.3). Individually, the indicators described below do not measure the resilience of the natural environment to the impacts of climate change. However, taken together as a package and interpreted in the context of resilience to climate change impacts, they can do.

Table 3.1 – Proposed list of indicators

Indicator	Diversity	Anth. pressure	Flexible management	Ecosystem services			
				Sup	Prov	Reg	Cult
Extent of semi natural habitat	✓	✓					
Land cover dominance and plant diversity	✓	✓					
Bird population indices	✓	✓			✓		
Landscape distinctiveness	✓						✓
Coastal habitat creation	✓					✓	
Good ecological status of WFD water bodies		✓				✓	✓
Abstractions		✓			✓		
Air quality		✓		✓			
Nitrogen deposition		✓					
Ecosystem fragmentation	✓	✓					
Area of land under conservation agreements			✓				
Progress in assessing / planning for climate change			✓				
Soil organic matter and soil organic carbon content				✓	✓	✓	
Area of functioning floodplain		✓				✓	
Area of green infrastructure within urban areas	✓				✓	✓	✓

3.2.1 Extent of semi-natural habitat

Why measure?

This indicator aims to measure the extent of semi-natural habitats. The greater the area of semi-natural habitat, the more flexible the natural environment is likely to be to change as the area for species to move into is greater. This indicator is linked to ecosystem fragmentation and land cover dominance; the extent of semi-natural habitat alone is not a measure of resilience, it is important to know how well connected it is, how dominant it is in the landscape and how sensitive resilience is to changes in connectivity.

How to measure

An annual figure of the area of semi-natural habitat in England should be calculated from the sum of the estimates of the different semi-natural habitats recorded in Natural England's State of the Environment report (Natural England 2008). These include grassland, wetland, coastal, heathland, woodland, standing water, marine, rock, arable and improved grassland. Within the State of the Environment 2008 report, estimates for grassland, wetland, coastal and heathland habitats outside Sites of Special Scientific Interest (SSSIs) are derived from Biodiversity Action Plan (BAP) priority habitat inventories. The extents of broadleaved woodland, and wood-pasture and parkland were derived from the Forestry Commission's Interpreted Forest Type data (Forestry Commission 2001) and historical wood-pasture and parkland data (Haines-Young 2007), respectively. Standing water data were derived from the Great Britain Lakes Inventory (Hughes *et al*. 2004) and canals from the Ordnance Survey 'Strategic' data. For marine habitats, the 'UK SeaMap - Seabed Landscapes' data (Connor *et al*. 2006) were used. The Countryside Survey 2000 (Haines- Young *et al*. 2000) was used to estimate the extent of broad habitat types, including inland rock, arable and improved grassland (Natural England 2008).

In addition to the State of the Environment report, data on the extent of BAP habitats can be obtained from the UK Biodiversity Action Partnership. Further information on the extent and current state of all ecosystems in the UK will be available as a result of the National Ecosystem Assessment. The Assessment will cover terrestrial, freshwater and marine ecosystems and full results will be available in 2011[3].

Interpretation

More semi-natural habitat means more space for species to move and adapt to climate change. Therefore an increase in this indicator would indicate increasing resilience.

3.2.2 Land cover dominance

Why measure?

This indicator aims to measure the diversity of land use. It will also provide a measure of plant diversity which can be used as an indicator of wider biodiversity, as plants form the basis of habitats for many other species. This indicator is closely linked to 'extent of semi-natural habitat' and 'ecosystem fragmentation'. At a national scale, a resilient natural environment is likely to include a range of land cover types and plant species and not be dominated by any one type. Diversity of land cover types and plant species is important as it increase the flexibility of the natural environment and allows species and landscapes to change in response to the impacts of climate change.

How to measure

The proportion of each of the 22 Broad Habitats recorded on the UK Land Cover Map should be reported as a percentage of the total UK surface area. The Broad Habitats have been linked to priority BAP habitats (Jackson 2000) which indicate the diversity of plant species likely to be found in each habitat type. This should give an indication of the range of land cover types and plant diversity and highlight any that are particularly dominant at a national scale.

Land Cover Maps have been created as part of Countryside Survey in 1990 and 2000, and will be produced again as part of the 2007 Survey (released in 2009). The Land Cover Maps are digital datasets constructed mainly from satellite images. Land Cover Map 2007 will show the stock and distribution of land cover and Broad Habitats across the UK (at a 'field by field' resolution, approx 0.5 hectare) (Countryside Survey)[4].

[3] http://www.unep-wcmc.org/eap/ukNationalEA.aspx

[4] Countryside Survey website http://www.countrysidesurvey.org.uk/land_cover_map.html#footnote

Interpretation

At a national scale, more diversity in land cover means greater adaptive capacity in the natural environment therefore a decrease in dominance would indicate increasing resilience.

3.2.3 Bird population indices

Why measure?

Birds are regarded as good indicators of the general health of wildlife and ecosystems as they are wide ranging in habitat distribution and tend to be at or near the top of the food chain (Furness & Greenwood 1993). This indicator is closely linked to the two previous indicators as bird populations are influenced by land use, vegetation and abundance of food (such as insects). As such, bird populations act as a proxy for many aspects of the natural environment. A monitoring framework for measuring bird populations is already in place and could be used to measure this indicator.

How to measure

This indicator is already used by Defra as part of the UK Sustainable Development Indicators and progress towards PSA targets. Bird population monitoring is undertaken by organisations such as the British Trust for Ornithology (BTO), the Royal Society for the Protection of Birds (RSPB) and the Wildfowl and Wetlands Trust (WWT). The results are expressed as an annual population index (relative to 1970) for the following classes of native bird populations:

- Upland birds;
- Lowland birds;
- Woodland birds;
- Wetland birds;
- Farmland birds; and
- Sea birds.

A change in the overall bird population index is interpreted as a change in biodiversity (i.e. an increase in the index represents an increase in biodiversity); a decrease in the indicator represents a decrease in biodiversity. Changes in the various classes of bird populations can represent other changes, e.g. a change in farmland birds can indicate change in agricultural land use, farming techniques and crop types. A change in wetland birds can indicate changes in water quality.

There is a risk of misinterpreting this indicator if the lists of bird species are not updated regularly. As climate changes new species are expected to move into the UK and others are expected to become rare or extinct. It is therefore necessary to add new-colonists to the list of species recorded under each class of birds if this indicator is to remain valid in future. Natural England should consult with the organisations responsible for monitoring bird populations to include new-colonists. Adding species to the classes of birds recorded may affect the consistency of the indicator but is vital to ensuring the indicator remains valid as climate change occurs (see Section 4 for further assessment of the indicator).

Interpretation

A resilient natural environment is characterised by high biodiversity therefore an increase in this indicator can be interpreted as an increase in resilience (assuming it includes non-native species).

3.2.4 Landscape distinctiveness

Why measure?

The combinations of landscape characteristics vary considerably from place to place and usually provide such a unique combination of components that landscapes are distinctive. This gives a sense of place and identity unique to each area (SNH 2005). Landscape distinctiveness is closely related to landcover dominance as habitat types are a component of landscape. Whilst it is recognised that the impacts of climate change may cause landscape change, it is important to retain distinctiveness.

How to measure

Information on landscape character is held at a national scale but it may be difficult to measure landscape distinctiveness from this data. It may be possible to measure landscape distinctiveness through qualitative surveys. However, this is likely to be time-consuming and the results will not be comparable over time.

Interpretation

An increase in landscape distinctiveness should be interpreted as an increase in resilience.

3.2.5 Coastal habitat creation

Why measure?

Coastal habitats are particularly vulnerable to the combined impacts of sea level rise, coastal erosion, salinisation and coastal squeeze. Adaptation at the coast is therefore vital to ensuring coastal habitats are resilient to change. Creating coastal habitats not only increases biodiversity, it increases the resilience of communities against flooding. It is also a more flexible way of managing flood risk than traditional hard engineered structures.

How to measure

Coastal squeeze to intertidal habitats is being addressed through intertidal habitat creation. Indeed the England Biodiversity strategy sets out an aspiration to restore saltmarsh to at least 1992 levels by 2015. The amount of intertidal habitat created should therefore be reported.

There is also a need to address the replacement of (mostly) freshwater habitats behind seawalls; to be resilient to climate change much of this will need to be re-created away from the coast inland. There are currently 32,000ha at risk in England. The amount of compensatory habitat creation in sustainable locations should therefore be reported. Whilst this habitat may no longer be at the coast, it is important to measure compensatory habitat to ensure there is no let loss of semi-natural habitat. This indicator is closely linked with the first indicator which measures the extent of semi-natural habitat.

The amount of intertidal habitat and compensatory habitat in sustainable locations should be measurable from Environment Agency returns to Defra. The Environment Agency compiles data on coastal habitat creation in order to fulfil its obligations under the European Habitat Regulation and Defra's High Level Targets. This reporting occurs every three years.

Interpretation

An increase in intertidal habitat and coastal habitat should be interpreted as an increase in resilience.

3.2.6 Good ecological status (of Water Framework Directive water bodies)

Why measure?

This indicator aims to measure the level of anthropogenic pressures acting on the natural environment. One of these pressures is poor water quality, often a result of nutrient loading from agriculture, industry and sewage treatment. Pressures such as these can significantly reduce the resilience of the natural environment to climate change and the ability to deliver ecosystem services such as water provisioning and recreation. Good ecological status is therefore a proxy for water quality but also biodiversity and ecosystem services.

How to measure

The number of water bodies in England achieving good ecological status should be reported. The Environment Agency is responsible for monitoring ecological status of freshwater bodies under the WFD. Achieving good ecological status depends on a combination of biological and chemical water quality, thus this is a good measure of the overall health of waterbodies.

Interpretation

A greater number of waterbodies achieving good ecological status indicates a reduction in anthropogenic pressures on the natural environment thus an increase in this indicator should be interpreted as an increase in resilience.

3.2.7 Abstractions from surface and groundwater

Why measure?

This indicator aims to measure the level of anthropogenic pressures acting on the natural environment. Sustainable use of water resources is required to ensure the natural environment is resilient to change and can continue to deliver ecosystem services. Abstractions from surface and groundwater where there are insufficient resources can put pressure on the natural environment and are unsustainable.

How to measure

The number of Water Resource Management Units (WRMUs) that are defined as 'over-abstracted' in the Environment Agency's Catchment Abstraction Management Strategies (CAMS) should be recorded.

Interpretation

A decrease in WRMUs defined as 'over abstracted' indicates a reduction in pressure on water resources. Therefore a decrease in this indicator should be interpreted as an increase in resilience of the natural environment.

3.2.8 Air quality

Why measure?

This indicator aims to measure the level of anthropogenic pressures acting on the natural environment and the provision of ecosystem services. External pressures such as poor air quality will reduce the ability of the natural environment to respond to climate change. For example, tropospheric ozone causes chlorosis and necrosis in plants and acid rain (as a result of air pollutants mixing with precipitation) results in acidification of soils and water. Air quality is a vital ecosystem service and poor air quality can leads to health problems in humans.

How to measure

Air quality is one of the UK Government's Indicators of Sustainable Development. The air quality indicator measures the average number of days on which pollution levels were above National Air Quality Standards. Whilst these standards are set primarily in the interests of public health, the pollutants they measure also have impacts on the natural environment. The National Air Quality Standards are thus acceptable for use in measurement of the resilience of the natural environment.

Interpretation

A decrease in the number of days on which air pollution levels are above National Air Quality Standards indicates an improvement in air quality. Therefore a decline in this indicator should be interpreted as an increase in resilience of the natural environment.

3.2.9 Nitrogen deposition

Why measure?

This indicator aims to measure the level of anthropogenic pressures acting on the natural environment. Whilst nitrogen deposition (the input of reactive nitrogen species from the atmosphere to the biosphere) is essential for plant growth, excessive amounts of nitrogen can have detrimental effects on the natural environment. Excessive nitrogen deposition can lead to acidification and eutrophication as well as increasing the risk of damage from abiotic factors, e.g. drought and frost. A change in the chemical environments of habitats from nitrogen deposition can also lead to changes in species composition via direct effects to sensitive species and cascading effects on the foodchain (Fenn *et al*. 2005). A high level of nitrogen deposition will reduce the resilience of the natural environment to the impacts of climate change.

How to measure

Nitrogen deposition is currently being measured through critical load mapping. Critical loads can be defined as: “a quantitative estimate of exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge” (Nilsson & Grennfelt, 1988). Additional deposition above the critical load is termed c**ritical load exceedance.**

Empirical nutrient nitrogen critical loads have been set for different ecosystem types. In the UK empirical nitrogen critical loads have been applied to unmanaged coniferous and broadleaved woodlands, grassland (acid and calcareous), dwarf shrub heath, bog, montane and some coastal habitats (Hall et al, 2004). Within each range of values for each habitat a “UK mapping value” has been set to provide a single value for the calculation of critical load exceedance. Critical load exceedance is mapped by comparing the critical load values with deposition values mapped at 5km resolution for the UK. The area of land in which the critical load is exceeded should be reported.

Interpretation

A decrease in nitrogen deposition indicates a reduction in anthropogenic pressure acting on the natural environment. A decrease in this indicator should therefore be interpreted as an increase in resilience.

3.2.10 Ecosystem fragmentation

Why measure?

This indicator aims to measure the extent to which England’s areas of semi-natural habitat are fragmented. It is strongly linked to the extent of semi-natural habitat and land cover dominance

indicators. A resilient natural environment should have habitats and ecosystems which are connected, allowing species to move in response to the impacts of climate change. Ecosystem connectivity can increase the adaptive capacity of the natural environment.

How to measure

An annual measure of the area covered by habitat networks should be reported. This can be obtained from the England Habitat Network which is used by Natural England to assess the level of fragmentation in the natural environment.

Interpretation

Highly fragmented ecosystems are unlikely to be able to adapt to the impacts of climate change. Therefore an increase in this indicator should be interpreted as a decrease in resilience.

3.2.11 Area / proportion of land under conservation agreements

Why measure?

It is important to know how much land is under conservation agreements as this is the land which Natural England has most control over and where it can implement climate change adaptation action. However, the nature of conservation activity is dependent on the prevailing conservation policy. Whilst present conservation policy may not always be consistent with delivering climate change adaptation, it is still useful to know how much land is under conservation agreements as this is the area where adaptation could be delivered if policy were to change. This indicator could be useful in influencing conservation policy to take account of climate change.

As current conservation agreements may be incompatible with the aims of adaptation to the impacts of climate change, the value of this indicator will need to be kept under review. It is recommended that Natural England start's with this indicator as worded here but converts it to 'area of land under adaptive conservation agreements' as soon as possible.

How to measure

An annual figure of land covered by conservation agreements should be reported. Conservation agreements should include land under Environmental Stewardship agreements and any of its predecessors (e.g. Environmentally Sensitive Areas scheme, Countryside Stewardship). Data on the area of land covered by Environmental Stewardship agreements can be found on the Natural England website and is available as GIS datasets.

Interpretation

An increase in the area of land under conservation agreements (assuming conservation policy is consistent with the aims of climate change adaptation) indicates the amount of land where Natural England can influence management to take account of the impacts of climate change and deliver adaptation. Therefore an increase in this indicator should be interpreted as an increase in resilience.

3.2.12 Planning for climate change

Why measure?

This is a process indicator which aims to measure the number of management plans that explicitly consider climate change and plan for adaptive management. In order to manage the natural environment for future conditions, management plans need to take account of and plan for the impacts of climate change. It is important that climate change response strategies take future uncertainty into account by implementing adaptive management. Adaptive management involves

responding to climate change through incremental change or modifying existing management practices in the face of uncertainty.

There is a risk that process indicators alone will lead to more management plans but not necessarily more adaptation action. This indicator measures adaptation planning rather than delivery and should therefore not be used in isolation to measure adaptation.

How to measure

The number of management plans and policies (which Natural England has influence over) that explicitly consider and plan for adaptive management should be reported. This indicator should cover any management plans produced by Natural England, e.g. site; habitat; species; landscape; historic environment; and geodiversity management plans. It should also include review of how Natural England is planning for SPAs, SACs, SSSIs and Environmental Stewardship. For each plan, the question 'does this plan consider and plan for adaptive management of the impacts of climate change?' should be asked and the answer recorded.

Interpretation

An increase in the number of management plans which take climate change into account and plan for adaptive management indicates an increase in flexible management. It also represents land where there is good environmental management and thus is likely to be more resilient.

3.2.13 Soil organic matter (SOM) and soil organic carbon (SOC) content

Why measure?

Organic matter has an influence on the chemical, physical and biological characteristics of soils. It affects plant growth through altering soil pH, assisting with a good structure for root growth, easing tillage, making soils more resistant to erosion and supplying nutrients. Changes in SOM content can affect the potential of soils to provide ecosystem services, for example: acting as a growing medium for food and fibre; water storage; buffering and transforming chemicals and providing a reservoir of biodiversity (Defra undated). An indicator of SOM is therefore a proxy for measuring ecosystem function and range of provisioning and regulating services.

In addition to these services, soils play a role in climate regulation as they are significant stores of carbon. Soil is a major component in the global carbon cycle and vulnerable to impacts of human activity.

How to measure

SOM is measured by Defra as part of the Sustainable Farming and Food Strategy. This indicator shows the levels of SOM in topsoils in different habitat type: woodland; grassland; heathland; and wetland. It is expressed as the grams of SOM per kilogramme.

SOC is measured by the Countryside Survey, last carried out in 2007. The Countryside Survey provides a national assessment of topsoil organic carbon amount (g cm-3).

Interpretation

An increase in SOM indicates increasing soil fertility and therefore an increase in ecosystem function. An increase in this indicator should therefore be interpreted as an increase in resilience. However, in some cases, low SOM is associated with high quality habitats. This indicator should therefore be used with caution if it applied at a local scale: it will be necessary to consider the specific habitat types present in the local area if this indicator is to remain meaningful.

An increase in SOC indicates increasing carbon storage which can be interpreted as an increase in resilience.

3.2.14 Area of functioning floodplain

Why measure?

The area of functioning floodplain is a good indicator for multiple resilience characteristics. It is an indicator of ecosystem structure and function as well as anthropogenic pressures. A functioning floodplain is vital for regulating flood risk but it also contributes to other services such as silt deposition, soil formation and providing a diverse ecosystem structure. The area of functioning floodplain is often constrained by development, thus is also a good indicator of anthropogenic pressures acting or the degree of naturalness in the natural environment.

The extent of floodplain is not a measure of the quality of the floodpain. This goes beyond what can be easily measured at the national scale but could be considered if the indicator is being used at a local or regional scale.

How to measure

The area of functional floodplain (as defined by the area of land classified as Flood Zone 3b by the Environment Agency) should be reported. This data should be available through the Environment Agency's Floodmap.

Interpretation

An increase in the area of functional floodplain can indicates an increase in ecosystem function and service as well as a reduction in anthropogenic pressures. An increase in this indicator should therefore be interpreted as an increase in resilience.

3.2.15 Area of green infrastructure within urban areas

Why measure?

Urban greenspace performs a number of services including providing a space for recreation, flood alleviation, local climate regulation and contributing to improved urban air quality. Urban green spaces also provide an important set of habitats, which exceed the area covered by conservation protective designations. The total area of urban greenspace is an indicator of these services.

How to measure

The area of green infrastructure in urban areas should be reported. This information should be available from local authorities.

Interpretation

An increase in the area or urban greenspace indicates an increase in the delivery of ecosystem services. Therefore an increase in this indicator should be interpreted as an increase in resilience.

4. Testing indicators

4.1 Literature review

Once potential indicators have been identified, they need to be tested to ensure they are fit for purpose. In order to test potential indicators, a list of evaluation criteria is required. The evaluation criteria should ensure that the indicators are measuring the characteristics of a resilient natural environment. Published lists of criteria on which indicators can be evaluated (UNCSD, 2001; ICES, 2002; EEA, 2003) are generally similar (Rice and Rochet 2005). Rice and Rochet (2005) summarise nine criteria which should be considered when testing indicators:

- Concreteness;
- Theoretical basis;
- Public awareness;
- Cost;
- Measurement;
- Historical data;
- Sensitivity;
- Responsiveness; and
- Specificity.

Several success factors relating to the use of indicators have been identified which can be used as evaluation criteria (Defra 2005). The success factors reflect many of the nine aspects listed above. Resilience indicators should (Defra 2005):

- Report progress over time;
- Be relatively few in number;
- Relate directly to the specific issue and impact classifications;
- Be consistent and comparable over time and space;
- Be clearly defined, understandable and usable;
- Be measurable – based as much as possible on existing routinely collected and quality-controlled data and accessible (input / output of the information system) at different levels (e.g. national, regional, municipal);
- Be transparent (e.g. composite indicators are less transparent, less useful for comparison, less useful for disentangling influence of actions); and
- Be acceptable for all stakeholders involved.

In addition to the success factors listed above, consultation with technical experts has revealed further important features of indicators which can be used to evaluate them. Indicators should:

- Assist in the identification of possible interactions with other sectors and partners: adaptation responses are likely to involve compromise between sectors (e.g. biodiversity and agriculture) and it will be necessary to work in partnership to deliver adaptation;
- Be sensitive to climate and socio-economic changes which affect the achievement of the desired objective;

- Be flexible: adaptation indicators, or the things they measure, should be able to change over time due to the uncertain nature of climate change impacts; and
- Provide measures that indicate relative progress towards achieving sustainable development.

4.2 Assessment criteria

Based on the literature review and consultation with technical experts, the following evaluation criteria for Natural England's climate change resilience indicators are suggested:

Does the indicator report progress towards the agreed objective over time?

It is important that the indicator can demonstrate whether the objective (a resilient natural environment) is being successfully delivered. It is less important to attribute change in an indicator to climate adaptation actions, given that resilience is about being able to adapt to a range of pressures and future changes.

Is the indicator consistent and comparable over time?

It is important that changes in the indicator can be compared over time given that adaptation is a long term process. However, it is important that indicators are flexible (see criterion above) given that the future is uncertain. If it is necessary to modify an indicator, care should be taken to ensure that previously collected data remains useful and comparable.

Is the indicator measurable?

It is important that mechanisms exist for collecting the data required to measure the indicator. As many of the indicators described above are taken from existing indicator sets, measurability should not be an issue but it should be considered when evaluating indicators.

Is the indicator easily understood?

It is important that the indicator (and the significance of changes in the indicator) is understood by non-scientists and decision makers. This is particularly important to ensure that Natural England and partners can use the indicators to influence conservation and adaptation policy.

Does what is being measured by the indicator contribute to sustainable development?

The UK Government is committed to embedding sustainable development in its policies, practice and operations through the cross-government Sustainable Development Programme. The purpose of the Programme is to implement the UK sustainable development strategy, 'Securing the Future' (HM Government 2005). The change measured by the indicator should contribute to the delivery of sustainable development objectives.

4.3 Other information

In addition to the assessment criteria which will be used to test and select indicators, it will be useful to collect additional information about the indicators. These are not criteria but questions which should be asked of every indicator to provide additional information.

Does the indicator measure something which Natural England and partners in the natural environment sector can influence directly?

It is useful to identify whether the indicator is measuring something Natural England, or its partners in the natural environment sector, has control over. Whilst it is important that Natural England can influence change in some of the indicators, it is not necessarily a problem if not. It is useful to identify where change in an indicator is controlled by the action of other sectors or organisations, as Natural England can identify partners for delivering resilience.

How does what the indicator is measuring interact with other sectors?

Action taken to increase resilience of the natural environment to the impacts of climate change is likely to interact with other sectors. Some of these interactions are likely to conflict with the objectives of other sectors and some are likely to be suitable for collaboration.

What is the shelf-life of the indicator and can it be modified?

Whilst useful now, some indicators may have limited applicability in future due to climate or socio-economic changes. There may come a point where indicators are no longer useful or they require modification in order to prolong their usefulness. Where these changes can be identified now, they should be recorded.

4.4 Testing indicators

Each of the indicators described in Section 3 has been assessed against the criteria (see Table 4.1) and other information questions (see Table 4.2). Where there are known problems with the indicators, these are highlighted in red. Potential problems are highlighted in orange and where an indicator has been assessed positively against the criteria, it is highlighted in green.

The majority perform well against the first criterion: there are only two indicators which do not measure resilience directly. There are a number of orange and red boxes in the consistency column; this is a result of the uncertain nature of climate change and the recognition that some definitions may change over the lifetime of the indicator. This could present problems in terms of consistency and comparability in time. However, the need for indicators to be flexible is crucial and indicators should not be rejected on the basis that they may change in future (see 'shelf-life' column in Table 3.2). It is important that the data collected prior to the change remains useful.

There are few problems identified with measurability of the indicators: most are already measured (although not always by Natural England). The indicator that may prove difficult to measure is landscape distinctiveness. There is currently no quantitative way of measuring this and it is likely that qualitative surveys would be necessary. This would be both time and resource intensive and may not produce comparable results. It could also be time consuming to measure 'progress in assessing and planning for climate change in the natural environment' as potentially every plan will have to be checked.

Existing indicators or measurements are likely to be easily understood as decision makers are likely to be familiar with them. The indicators which may be more difficult to interpret are those which do not directly measure resilience e.g. 'area of land under conservation agreement' and 'progress in assessing and planning for climate change'.

The majority of indicators are measuring actions which contribute to sustainable development although the two indicators which measure resilience indirectly perform less well against this criterion.

A number of potential limitations to the shelf-life of the indicators (as currently worded) have been identified, along with points at which they may need to be modified e.g. bird population indices and good ecological status of WFD waterbodies. There are some indicators which may have a limited shelf-life; this is not necessarily a problem as they all measure something useful now. Indicators need to remain flexible in the face of uncertain climate and socio-economic change; therefore, recognising points at which they may need to be modified is important. The 'shelf-life' column in Table 4.2 identifies a number of points where the proposed indicators will need modification. It is crucial that indicators are reviewed periodically to ensure they are still fit-for-purpose.

Change in all the indicators represent implications for other sectors in one way or another, some of these interactions may conflict with Natural England's adaptation objectives while some may

compliment each other. By assessing and identifying potential interactions, Natural England can identify possible partners or stakeholders in adaptation of the natural environment.

Table 4.4.1 – Testing indicators

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Extent of semi-natural habitat	More semi-natural habitat means more space for species to move and adapt to climate change therefore an increase in this indicator would indicate increasing resilience.	If the definition of semi-natural habitat was to change or more habitats were monitored as part of the State of the Natural Environment report this indicator would need to be modified and may no longer be comparable over time.	State of the Natural Environment Report includes data on habitat extent (broken down by habitat types). The total area of semi-natural habitat should be summed from these figures.	Should be easily understood - is a familiar indicator (although interpretation of it is slightly different in this context).	The activity this indicator measures contributes to sustainable development.
Landcover dominance and plant diversity	More diversity in land cover means greater adaptive capacity in the natural environment therefore a decrease in dominance would indicate increasing resilience. However this may not be true at all scales.	This indicator should remain comparable over time but may not be comparable in space, depending on the scale of use. Interpretation may be different at different scales.	Land Cover Maps have been created as part of Countryside Survey in 1990 and 2000, and will be produced again as part of the 2007 Survey (released in 2009).	May not be well understood as this is a new indicator.	The activity this indicator measures contributes to sustainable development.
Bird populations	A resilient natural environment is characterised by high biodiversity therefore an increase in this indicator can be interpreted as an increase in resilience (assuming it includes new-colonist species).	This indicator may not be comparable over time as the species used to measure it may change.	This indicator is already used by Defra as part of the UK Sustainable Development Indicators and progress towards PSA targets. Bird population monitoring is undertaken by organisations such as the British Trust for Ornithology (BTO), the Royal Society for the Protection of Birds (RSPB) and the Wildfowl and Wetlands Trust (WWT).	Should be easily understood - is a familiar indicator (although interpretation of it is slightly different in this context).	The activity this indicator measures contributes to sustainable development.

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Landscape distinctiveness	Greater landscape distinctiveness should be interpreted as an increase in resilience.	This indicator may be difficult to compare over time as data are purely qualitative. May require survey data – consistency may depend on type of questions asked.	This indicator may be difficult to measure as distinctiveness can only be described qualitatively. May require survey data – resource intensive.	This indicator may be difficult to understand as it will not be possible to quantify – difficult to see how it can be used to influence policy.	An increase in landscape distinctiveness would contribute to sustainable development.
Coastal habitat creation	An increase in intertidal and compensatory habitat should be interpreted as an increase in resilience. Although some compensatory habitat might not be at the coast, it is important to measure this to ensure there is no net loss of semi-natural habitat.	Should be comparable over time.	The Environment Agency holds information on area of SAC, SPA and BAP habitat created. Data only available at three yearly intervals so will not be able to compare on an annual basis.	Based on existing measurements so should be easily understood.	The activity this indicator measures contributes to sustainable development.
Good ecological status of WFD water bodies	A greater number of waterbodies achieving good ecological status indicates a reduction in anthropogenic pressures on the natural environment thus an increase in this indicator should be interpreted as an increase in resilience.	This indicator may not remain comparable over time if the definition of 'good ecological status' changes or if reference conditions alter significantly. Currently the WFD reference conditions do not account for climate change therefore the usefulness of this indicator over time is questionable unless a moving baseline with respect to the reference conditions is adopted.	The Environment Agency is responsible for monitoring ecological status of freshwater bodies under the Water Framework Directive. However, there will potentially be a lot of data to compile in order to report this indicator.	Should be easily understood - is a familiar indicator.	The activity this indicator measures contributes to sustainable development.

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Abstraction from surface and ground water	A decrease in WRMUs defined as ‘over abstracted’ indicates a reduction in pressure on water resources. Therefore a decrease in this indicator should be interpreted as an increase in resilience of the natural environment.	This indicator may not remain comparable over time if the definition of 'over abstracted' changes.	The number of WRMUs that are defined as ‘over-abstracted’ in the Environment Agency’s CAMS should be recorded.	Should be easily understood - is a familiar measure.	The activity this indicator measures contributes to sustainable development.
Air quality	A decrease in the number of days on which air pollution levels are above National Air Quality Standards indicates an improvement in air quality. Therefore a decline in this indicator should be interpreted as an increase in resilience of the natural environment. The National Air Quality Standards are based on health considerations rather than the requirements of the natural environment so this may not be well suited to Natural England’s purpose.	This indicator may not remain comparable over time as National Air Quality Standards change.	Air quality is one of the UK Government's Indicators of Sustainable Development. The air quality indicator measures the average number of days on which pollution levels were above National Air Quality Standards.	Should be easily understood - is a familiar indicator.	The activity this indicator measures contributes to sustainable development.
Nitrogen deposition	A decrease in nitrogen deposition indicates a reduction in anthropogenic pressure acting on the natural environment. A decrease in this indicator should therefore be interpreted as an increase in resilience.	This indicator should remain comparable over time.	Nitrogen deposition is currently measured by critical load exceedence mapping. This can be used to report on this indicator.	Should be easily understood - is a familiar measurement.	The activity this indicator measures contributes to sustainable development.

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Ecosystem fragmentation	The greater the extent of fragmentation, the lesser the adaptive capacity of the natural environment. Therefore a decrease in this indicator should be interpreted as an increase in resilience.	This indicator should remain comparable over time.	England Habitat Network. Currently only limited to a few habitat types so unlikely to be comprehensive.	May not be well understood as habitat networks are a fairly new concept.	The activity this indicator measures contributes to sustainable development.
Area of land under conservation agreement	This indicator does not measure resilience directly - an increase in the area of land under conservation agreements does not necessarily mean resilience is being increased. What it does do is indicate the amount of land where Natural England can influence management to take account of the impacts of climate change and deliver adaptation (subject to conservation policy). There is scope for this indicator to be more useful in future if policy is consistent with the aims of adaptation. It is therefore recommended that Natural England includes this indicator in its first package of indicators but converts it to 'Area of land under adaptive conservation agreements' as soon as possible.	This indicator should remain comparable over time as the exact nature of the conservation agreement does not matter. It could be extended to look at the quality of adaptation.	Data on the area of land covered by Environmental Stewardship agreements can be found on the Natural England website and are available as GIS datasets.	This indicator is less easy to understand as a change in the indicator doesn't necessarily mean resilience of the natural environment is being increased - this depends on the nature of conservation policy.	This indicator does not measure sustainable development directly - that depends on the nature of conservation policy. It gives an indication of where sustainable development could be delivered.

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Progress in assessing and planning for climate change	An increase in the number of management plans which take climate change into account and plan for adaptive management does not directly indicate an increase in resilience as action on the ground may not have been taken.	This indicator is new; therefore, no comparison can be made before 2009 (or whenever the indicators are adopted). From this point it should remain comparable.	This indicator is not currently monitored. It may be time consuming to review all management plans – selection may be required.	New indicator but should be easy to understand.	This indicator does not contribute directly to delivery of sustainable development - it measures progress towards planning for climate change rather than implementation of adaptation.
Soil organic matter content and soil carbon content	An increase in SOM indicates increasing soil fertility and therefore an increase in ecosystem function. However, low SOM content is typical of most good quality wildlife sites so this may not always be a useful indicator. An increase in SOC represents an increase in delivery of ecosystem services so should be interpreted as contributing to an increase in resilience.	This indicator should remain comparable over time.	SOM and SOC are measured by Defra as part of the Sustainable Farming and Food Strategy.	Should be easily understood - is a familiar indicator.	The activity this indicator measures contributes to sustainable development.
Area of functioning floodplain	An increase in the area of functional floodplain indicates a potential increase in ecosystem function and service as well as a reduction in anthropogenic pressures. An increase in this indicator should therefore be interpreted as an increase in resilience.	This indicator is new; therefore, no comparison can be made before 2009 (or whenever the indicators are adopted). From this point it should remain comparable.	Data should be available through the Environment Agency's Floodmap. However, it may be difficult to reliably identify the extent of the 'functional' floodplain as opposed to simply the floodplain itself.	May not be well understood as this is a new indicator.	The activity this indicator measures contributes to sustainable development.

Indicator	Progress towards objective	Consistency	Measurability	Easily understood	Sustainable development
Area of greenspace within urban areas	An increase in the amount of greenspace within urban areas indicates improving ecosystem services. Therefore an increase in this indicator should be interpreted as a positive change.	This indicator should remain comparable over time.	This should be measurable from local authority data.	Should be easily understood - is a familiar indicator.	The activity this indicator measures contributes to sustainable development.

Table 4.4.2 – Other information

Indicator	Shelf-life	Interactions with other sectors	Natural England influence
Extent of semi-natural habitat	As climate changes habitat extent is likely to change - it is the amount of semi-natural habitat rather than particular habitats that this indicator is measuring. This indicator should therefore remain useful regardless of what habitats are present.	Changes in this indicator may affect other sectors, e.g. agriculture, development. More semi-natural habitat means less land available for these purposes.	Natural England has influence over the amount of semi-natural habitat present through its role in managing SSSIs and other designated sites and agri-environment schemes. Additional partners include the Environment Agency, Wildlife Trusts, RSPB, and the Forestry Commission.
Landcover dominance and plant diversity	As climate changes landcover is likely to change - it is the diversity of landcover rather than particular landcover that this indicator is measuring. This indicator should therefore remain useful regardless of what landscapes are present.	Changes in this indicator may affect other sectors which can contribute to low diversity in land cover, e.g. agriculture.	Natural England has influence over land cover through management of SSSIs and other designated sites and agri-environment schemes. Additional partners include other natural environment organisations, farmers, industry and planners.
Bird population indices	As climate changes new species are expected to move into the UK. It is therefore necessary to add new-colonist species to the classes of birds monitored if this indicator is to remain valid in future.	Changes in this indicator are likely to represent implications for other sectors including agriculture.	Natural England has influence over bird populations through its role in managing SSSIs and other designated sites and agri-environment schemes. Additional partners include the Environment Agency, Wildlife Trusts, RSPB, Forestry Commission, farmers and industry.
Landscape distinctiveness	As climate changes landscapes are likely to change - it is the distinctiveness of landscapes rather than particular landscapes that this indicator is measuring. This indicator should therefore remain useful regardless of what landscapes are present.	Changes in this indicator are likely to result in positive interactions with access and recreation and the cultural services performed by the natural environment.	Natural England has influence over this indicator through management of SSSIs and other designated sites and agri-environment schemes.
Coastal habitat creation	As climate changes coastal habitats are likely to change - it is the amount of coastal habitat rather than particular habitats that this indicator is measuring. This indicator should therefore remain useful regardless of what coastal habitats are present.	Changes in this indicator may affect other sectors e.g. agriculture, development. More semi-natural habitat means less land available for these purposes. Positive impact on coastal flood defence (for areas behind the coastal habitat).	Natural England has influence over this indicator through management of SSSIs and other designated sites and agri-environment schemes. The Environment Agency is responsible for coastal flood defence and habitat creation.

Indicator	Shelf-life	Interactions with other sectors	Natural England influence
Good ecological status	The usefulness of this indicator depends on the reference conditions used to define 'good ecological status'. Reference conditions will change over time as the impacts of climate change manifest themselves and water ecosystems adapt. However, currently the WFD reference conditions do not account for climate change therefore the usefulness of this indicator over time is questionable as it stands. If a moving baseline is adopted, the life of this indicator will be prolonged.	Change in this indicator may affect other sectors - e.g. positive effects for water companies due to lower treatment requirements, higher costs for water companies and industry due to increasing treatment requirements, increase in GHG emissions due to increasing treatment requirements.	The Environment Agency is responsible for implementing the Water Framework Directive in England and monitoring water quality. The definition of 'good ecological status' is set by the European Commission. Natural England has influence over ecological status of waterbodies through management of SSSIs and other designated sites and agri-environment schemes. Additional partners include the Environment Agency, water companies, farmers and industry.
Abstraction from surface and ground water	This indicator remains valid until the point where abstractions are no longer a concern in the natural environment.	Change in this indicator may affect other sectors which demand water, e.g. potable supply, agriculture, industry.	The Environment Agency is responsible for regulating and monitoring abstraction. Natural England can influence abstraction management through CAMS consultation.
Air quality	This indicator may need to be modified depending on the definition of national air quality standards. This indicator remains valid until the point where air quality is sufficiently high that it is no longer a concern in the natural environment.	Change in this indicator may affect other sectors - e.g. positive effects on health, higher costs for industry due to increasing treatment requirements, increase in GHG emissions due to increasing treatment requirements.	The Environment Agency is responsible for regulating emissions to air.
Nitrogen deposition	This indicator remains valid until the point where nitrogen deposition is no longer a concern.	Change in this indicator may affect other sectors - e.g. positive effects on health, higher costs for industry due to increasing treatment requirements, increase in GHG emissions due to increasing treatment requirements.	The Environment Agency is responsible for regulating air and water pollution. Other partners include farmers, water companies, and industry.
Ecosystem fragmentation	As climate changes habitat networks are likely to change - it is the extent of networks rather than particular habitat networks that this indicator is measuring. This indicator should therefore remain useful regardless of what habitats are present.	Changes in this indicator may affect other sectors, e.g. agriculture, development. More land under conservation agreements means less land available for these purposes.	Natural England can influence ecosystem connectivity through management of SSSIs and other designated sites as well as agri-environment schemes. Other partners include the Environment Agency, Wildlife Trusts, RSPB, Forestry Commission, farmers and planners.

Indicator	Shelf-life	Interactions with other sectors	Natural England influence
Area of land under conservation agreements	This indicator remains valid so long as conservation agreements are in place (although it does not matter what the nature of these agreements are i.e. it remains valid if Environmental Stewardship is replaced with another scheme). The usefulness of this indicator increases if conservation policy is consistent with the aims of adaptation therefore this should be used to influence policy. The usefulness of this indicator depends on the nature of conservation policy – many current policies are incompatible with the aims of adaptation. It is therefore recommended that Natural England includes this indicator in its first package of indicators but converts it to 'Area of land under adaptive conservation agreements' as soon as possible.	Change in this indicator is likely to interact significantly with agriculture and the planning system.	Natural England can influence this through agri-environment schemes. Natural England should seek to influence conservation policy to take account of climate change through liaison with Defra and DECC.
Progress in assessing and planning for climate change	This indicator remains valid until the point where all management plans take account of climate change and plan for adaptation. At this point it is no longer required or the focus will need to shift to measuring quality of adaptation.	Change in this indicator is likely to result in few effects in other sectors - implementation of plans may do though.	Natural England can directly influence planning for climate change in the management plans for SSSIs and other designated sites it is responsible for. Partnership with other bodies such as National Parks, AONBs, Wildlife Trusts, RSPB and Forestry Commission.
Soil organic matter and soil organic carbon	This indicator should remain valid in perpetuity.	Changes in this indicator are likely to affect on agriculture.	Natural England can influence soil organic matter content through management of SSSIs and other designated sites as well as agri-environment schemes. Other partners include farmers.
Area of functioning floodplain	This indicator should remain valid in perpetuity.	Positive impact on water resources, water quality, flood protection. Negative impacts on development which may wish to locate here.	The Environment Agency is a statutory consultee in planning decisions in floodplains; therefore, it is more likely to be able to influence this indicator than Natural England.

Indicator	Shelf-life	Interactions with other sectors	Natural England influence
Area of greenspace within urban areas	This indicator remains valid.	Potentially positive effects on health.	Greatest influence over this indicator is likely to come from the planning sector and local authorities.

4.5 Selection of indicators

The selection of indicators should aim to identify indicators that perform well against all criteria. If none of the indicators performs well against all criteria, then the suite of selected indicators should balance strengths and weaknesses so that all criteria are covered (Rice and Rochet 2005). It is clear from Tables 4.1 and 4.2 that all the indicators have strengths and weaknesses. These are summarised in Table 4.3.

Following the assessment of the indicators, only one has been identified as being particularly problematic – landscape distinctiveness. This is due to the qualitative nature of what the indicator is trying to measure. It is very difficult to identify a consistent, comparable source of data on landscape distinctiveness at a national scale. It is likely that this data could only be collected through qualitative surveys which would produce large amounts of data that could not be easily reported. As a result, it is recommended that 'landscape distinctiveness' is not taken forward as an indicator of resilience in the natural environment.

There may be a problem with the 'area of land under conservation agreements' indicator as some current conservation policies may be incompatible with the aims of adaptation. It is therefore recommended that Natural England includes this indicator in its first package of indicators but converts it to 'area of land under adaptive conservation agreements' as soon as possible.

Table 4.4.3 – Strengths and weaknesses of indicators

Indicator	Strengths	Weaknesses
Extent of semi-natural habitat	Existing indicator and is measurable, comparable and well understood	
Landcover dominance and plant diversity	Existing measure and is comparable	May be difficult to understand
Bird population indices	Existing indicator and is measurable, comparable and well understood	Depends on bird species monitored – need to include newly arriving species therefore limited shelf life as written
Landscape distinctiveness	Reduces biodiversity focus of indicator set – includes other functions of Natural England	Qualitative indicator therefore may be difficult to interpret, understand and compare through time. No easily identifiable mechanism for measuring this indicator.
Coastal habitat creation	Existing measure and is comparable and well understood	Compensatory habitat may not be at the coast (although there is still value in measuring the amount of semi-natural habitat created).
Good ecological status of WFD water bodies.	Existing indicator and is measurable, comparable and well understood	Depends on definition of 'good ecological status' which will need to be flexible to account for climate change (and is not defined by Natural England).
Abstractions from surface and ground waters	Existing measure and is comparable and well understood	Depends on definition of 'over abstracted' which is not controlled by Natural England

Indicator	Strengths	Weaknesses
Air quality	Existing indicator therefore is measurable, comparable and well understood	Depends on definition of National Air Quality standards which are not controlled by Natural England
Nitrogen deposition	Should remain comparable over time and no (foreseeable) limit to shelf-life Already measured by critical load mapping.	Could be difficult to understand as critical load mapping is a relatively new concept
Ecosystem fragmentation	Measures a number of characteristics – diversity, ecosystem functioning, anthropogenic pressures	Could be difficult to understand as networks are a relatively new concept
Area of land under conservation agreements	Measures a range of characteristics – diversity, anthropogenic pressure, provisioning services	Does not measure adaptation or contribution to sustainable development directly
Progress in assessing and planning for climate change	Only process indicator	Does not measure adaptation or contribution to sustainable development directly
Soil organic matter content and soil carbon content	Existing indicator therefore is measurable, comparable and well understood No (foreseeable) limit to shelf-life	
Area of functioning floodplain	Measures a range of characteristics – ecosystem structure, regulating services and anthropogenic pressures	It may be difficult to reliably identify the extent of the 'functional' floodplain as opposed to simply the floodplain itself.
Area of urban greenspace	Is more urban focused – majority of indicators are rural focused	

As a result of the evaluation process, the following indicators are suggested to form a package of climate change adaptation indicators for the natural environment:

- Extent of semi-natural habitats;
- Landcover dominance and plant diversity;
- Bird population indices;
- Coastal habitat creation;
- Good ecological status of WFD water bodies;
- Abstraction from surface and groundwaters;
- Air quality;
- Nitrogen deposition;
- Ecosystem fragmentation;
- Area of land under conservation agreements;
- Progress in assessing and planning for climate change;

- Soil organic matter content and soil organic carbon content;
- Area of functioning floodplain; and
- Area of urban greenspace.

5. Further work

The results of this project are the first step in providing Defra with indicators of adaptation in the natural environment. Further work is required to develop the findings of this project. A number of areas for further work have been identified:

- Evaluation of further suggestions from commentators (see below);
- Identification of areas which are not measured by existing indicator sets or for which existing indicators are not suitable;
- Suggestion of further work required to fill these gaps;
- Interpretation of the indicator package and how to distil this to a single indicator; and
- How to use the approach to identify regional indicators of resilience.

5.1 Further indicators for evaluation

Commentators on this report have suggested further indicators for evaluation. These include:

- Heat island effect – measuring the temperature differential between urban areas and surrounding countryside. This would measure the extent to which 'natural air conditioning' ecosystem services have been stripped out of urban environments or retained as 'green infrastructure';
- Plant diversity – measure the diversity of plant species, possibly through the Countryside Survey. Plants form habitats for many other species so are a useful indicator of wider diversity and ecosystem function;
- Human mortality and morbidity from extreme weather events – an increase in this indicator can be interpreted as a breakdown of ecosystem services; and
- Extent of protected marine habitats – an indicator to measure the amount of marine habitat covered by designations such as Marine Protected Area (MPA) or no-take zones. An increase in this indicator would be interpreted as an increase in resilience of the marine environment.

These indicators require evaluation against the criteria set out in Section 4.2 before being included in the indicator package. As they are all new indicators or measurements (i.e. not part of an existing indicator set), they may require further development before they are included in the indicator package.

5.2 Gaps

The project has identified a package of indicators based on literature review and discussion of existing indicator sets and measurements of the natural environment. The indictors are designed to measure the characteristics of a resilient natural environment and to cover all of Natural England's functions. Throughout the course of the project a number of gaps where there are no suitable existing indicators have also been identified. The main gaps are:

- Cultural services;
- Landscape; and
- Marine environments.

5.2.1 Cultural services

Access and recreation and understanding and appreciating nature are cultural services provided by ecosystems. It has been agreed that resilient natural environments deliver ecosystem services and as such, cultural ecosystem services should be included in an indicator package.

There are a number of existing indicators and empirical datasets which can be used to measure access and recreation. However, access and recreation may not be consistent with the aims of adaptation and may reduce resilience of the natural environment. Increasing access to the natural environment may have a negative impact on the other characteristics of a resilient natural environment.

Further work is required to identify indicators of access and recreation which are consistent with the aims of adaptation. Consultation with socio-economic and ecosystem services specialists within and outside Natural England would be the first step in identifying these indicators. It may be necessary to determine a threshold at which access becomes detrimental to resilience although this is likely to vary by location and will be difficult to determine at a strategic level.

Understanding and appreciating nature is the other aspect of cultural ecosystem services alongside access. An indicator for understanding and appreciating nature is required to balance and complete the measurement of ecosystem services. Natural England is currently developing a set of 'natural environment engagement' questions to form part of the Monitoring and Engagement with Natural Environment (MENE) survey. This will be the major primary national data source on Natural England's Outcome 2 and may provide what is needed for an 'understanding and appreciating nature' indicator. The first step in identifying this indicator would be consultation with Natural England staff developing the MENE survey.

5.2.2 Landscape

One of the characteristics of a resilient natural environment is diversity, including diversity in landscape. Landscapes also provide a number of ecosystem services, particularly cultural services. However, as a result of the evaluation process, the 'landscape distinctiveness' indicator was removed from the final selection and no suitable alternative has been found. This is largely due to the qualitative nature of landscape: it does not lend itself to measurement with a quantitative indicator. Further work is required to identify an indicator of landscape distinctiveness or the cultural service delivered by landscapes. The first step in identifying a landscape indicator would be consultation with landscape specialists from Natural England and other organisations.

5.2.3 Marine environments

Natural England's remit covers marine habitats as well as terrestrial, freshwater and coastal habitats. As such, the indicator package should include indicators which measure the resilience of the marine environment. The only proposed indicator which currently considers any aspect of the marine environment is the bird population index indicator. A further possible marine indicator for evaluation is suggested in Section 5.1.

The characteristics of a resilient natural environment as defined in Section 2.2.2 are likely to be applicable to a resilient marine environment. Further work is required to identity indicators of these characteristics in the marine environment. This should adopt a similar method to that followed in this project: literature review of existing marine indicator sets and consultation with marine environment specialists.

5.3 Interpretation of indicator package

The complexity of the natural environment makes it very difficult to devise a single indicator that represents resilience to the impacts of climate change. The outcome of this project is, therefore, a package of indicators which, taken together, measure the resilience of the natural environment to the impacts of climate change (and other changes). An indication of how to interpret each indicator in the context of resilience is given. However, more thought needs to be given to how the package should be interpreted as a whole: if some indicators increase but some decrease, what is the overall impact on resilience of the natural environment? At the moment there is no way of answering this question as no measure of importance is attached to the indicators. An assumption of equal importance or a weighting scheme would be needed if a single expression of resilience made up of the component indicators is to be given.

One way of expressing the indicator package as a single number might be a resilience score. Work has been carried out to assess the vulnerability of different receptors to the impacts of climate change and this has been expressed as a vulnerability score. For example, Maplecroft's climate change scorecards indicate the relative vulnerability of countries to the impacts of climate change by using a vulnerability index made up of a number of component indicators[5]. Research has also been carried out to create an index which expresses relative levels of social vulnerability to climate change-induced variations in water availability (Vincent 2004).

It may be possible to use an index approach to express resilience in the natural environment. The component indicators would have to be ranked in terms of importance of the contribution of what they are measuring to resilience. An increase or decrease in each indicator would then be given a score which would be multiplied by the weighting factor. The weighted scores would be summed to give an overall resilience score which could be compared annually.

To progress this approach, the following further work is likely to be necessary:

- Literature review of projects which have used a vulnerability index to express vulnerability to climate change to better understand the method used to weight indicators;
- Further consultation with the group of technical specialists to rank the indicators (or what the indicators measure) in terms of order of importance with respect to their contribution to resilience of the natural environment;
- Determination of scores to be awarded for an increase or decrease in each indicator (e.g. will a simple scoring system (+1 / 0 / -1) be applicable or is a more complex scoring depending on extent of increase or decrease required); and
- Trial run of scoring / weighting system to derive a single measure of resilience of the natural environment.

5.4 Regional approach

The indicators presented in this report are intended for use at a strategic level rather a local or regional scale. However, the framework used to identify indicators should be applicable at all scales. The desired objective and characteristics of a resilient natural environment should remain the same at all scales. However, regions could alter these to suit their purposes or the features present in the region. The identification of indicators should follow a similar method although it is likely that there are fewer existing sets of indicators at a regional level. It may be necessary to tweak the wording of the national scale indicators in order to make them relevant to the regional context.

[5] http://www.maplecroft.net/Maplecroft_climate_change.pdf

The indicators presented in this report focus on measuring the extent of the characteristics and no judgement has been made about the relative value of different habitats, species, services etc. Under the 'extent of semi-natural habitat' indicator, for example, no judgement is made about which habitats are more valuable than others; it is only concerned with the aggregate amount of semi-natural habitat present. However, if these indicators were to be used at a regional or local scale, they could be adapted to take account of local habitat, species or ecosystem services priorities. For example, if measuring adaptation in a lowland area where chalk grassland habitat is valued above woodland habitat, the 'extent of semi-natural habitat' indicator could be change to 'extent of grassland habitat'. An increase in this indicator would then be interpreted as an increase in resilience in that area.

Evaluation of indicators should follow the same method as that used in this project although there may be a need for regions to tailor the assessment criteria to regional priorities.

Further work will be required to test the methodology for identifying indicators at a regional level. It is suggested that one region trials the method presented in this report. The lessons leant in that region should then be used to modify the methodology to make it more suitable for use at a regional scale if necessary.

5.5 Summary of further work

The further work suggested in this chapter is summarised in Table 5.1 below.

Table 5.1 – Suggested further work

Area for further work	Suggested tasks
Further indicators for evaluation	• Develop the suggested indicators using the template provided in this report i.e. for each one describe why it is a good indicator, how to measure it and how to interpret it. • Evaluate the suggested indicators against the criteria set out in this report. • Assess whether the suggested indicators should be included in the indicator package.
Cultural services	• Consultation with socio-economic and ecosystem services specialists within and outside Natural England. • Consultation with Natural England staff developing the MENE survey. • Review existing cultural service indicator sets.
Landscape	• Consultation with landscape specialists from Natural England and other organisations
Marine environments	• Literature review of existing marine indicator sets • Consultation with marine specialists from Natural England and other organisations

Area for further work	Suggested tasks
Interpretation of the indicator package	• Literature review of projects which have used a vulnerability index to express vulnerability to climate change to better understand the method used to weight indicators. • Further consultation with the group of technical specialists to rank the indicators (or what the indicators measure) in terms of order of importance with respect to their contribution to resilience of the natural environment. • Determination of scores to be awarded for an increase or decrease in each indicator (e.g. will a simple scoring system (+1 / 0 / -1) be applicable or is a more complex scoring depending on extent of increase or decrease required)? • Trial run of scoring / weighting system to derive a single measure of resilience of the natural environment.
Regional approach	• Literature review of regional indicator sets • Trial methodology in one region • Use the lessons learnt form the trial region to refine the methodology

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Appendix A

A.1 Existing indicators

Table A.1 – Potential indicators from existing indicator sets

Characteristic	Indicator	How it measures characteristic	Source
Diversity	Proportion of Local Sites where active conservation management is being achieved	Active conservation management indicates an attempt to improve the condition of sites	Local government performance indicator NI187
	Abundance and distribution of selected species	A resilient natural environment should be diverse as this increases the ability of species composition to change in response to climate change	Streamlining European 2010 Biodiversity Indicators (SEBI)
	Sites designated under the EU Habitats and Birds Directives	Designated sites are likely to be the foci of management which aims to maintain or increase biodiversity	SEBI
	Ecosystem coverage	A resilient natural environment should be diverse in terms of habitats as this increases the ability of species to move and adapt to the impacts of climate change	SEBI
	Designated areas	Designated sites are likely to be the foci of management which aims to maintain or increase biodiversity	European Environment Agency (EEA) Core indicators
	Species diversity	A resilient natural environment should be diverse as this increases the ability of species composition to change in response to climate change	EEA Core indicators
	Threatened and protected species	Measures populations of threatened and protected species – will indicate where biodiversity is being lost	EEA Core indicators
	Bird population indices: farmland birds; woodland birds; seabirds	Birds are regarded as good general indicators of the general health of wildlife and ecosystems and a measure of biodiversity	UK Sustainable Development indicators
	Bringing into favourable condition by 2010 95 per cent of all nationally important wildlife sites	Measure to bring sites into favourable condition can maintain or enhance biodiversity	Defra Public Service Agreement (PSA) targets

Characteristic	Indicator	How it measures characteristic	Source
	Wild bird populations	Birds are regarded as good general indicators of the general health of wildlife and ecosystems	Environment Agency indicators
	Otter occurrence	Measures populations of a protected species – may not be a good indicator of wider biodiversity but may indicate water quality	Environment Agency indicators
Anthropogenic pressures within carrying capacity	Critical load exceedence for nitrogen	Measures water quality and eutrophication (a significant pressure on freshwater systems). Critical loads are also used to measure impacts on terrestrial systems e.g. acidification.	SEBI
	Invasive alien species	A measure of invasive species can indicate pressure on an ecosystem.	SEBI
	Freshwater quality	A measure of health of freshwater habitats	SEBI
	Exposure of ecosystems to acidification, eutrophication and ozone	Measures water and air quality pressures	EEA Core indicators
	Land take	Measures pressure on land resources	EEA Core indicators
	Progress in management of contaminated sites	Contaminated land is a significant pressure on the natural environment	EEA Core indicators
	Nutrients in freshwater	Measures water quality and eutrophication (a significant pressure on freshwater systems)	EEA Core indicators
	Oxygen consuming substances in rivers	Measures water quality and eutrophication (a significant pressure on freshwater systems)	EEA Core indicators
	Urban waste water treatment	Measures water quality and eutrophication (a significant pressure on freshwater systems)	EEA Core indicators
	Use of freshwater resources	May indicate where abstractions limit water for use in natural environment	EEA Core indicators
	Total abstractions from non-tidal surface and ground water	May indicate where abstractions limit water for use in natural environment	UK Sustainable Development Indicators

Characteristic	Indicator	How it measures characteristic	Source
	Resource availability status at low flows for units of surface water and / or surface water combined with groundwater	May indicate where abstractions limit water for use in natural environment	UK Sustainable Development Indicators
	Fertiliser input	Measures nutrient enrichment and possible eutrophication (a significant pressure on freshwater systems)	UK Sustainable Development Indicators
	Area of sensitive UK habitats exceeding critical loads for acidification and eutrophication	Measures nutrient enrichment and possible eutrophication (a significant pressure on freshwater systems). Critical loads are also used to measure impacts on terrestrial systems.	UK Sustainable Development Indicators
	Dangerous substances in water	Contaminated water is a significant pressure on freshwater ecosystems	Environment Agency indicators
	Pesticide use in agriculture and horticulture	Measures nutrient enrichment and possible eutrophication (a significant pressure on freshwater systems)	Environment Agency indicators
	Soil loss to development	Soil performs a vital provisioning service	Environment Agency indicators
	Nutrients in rivers	Measures water quality and eutrophication (a significant pressure on freshwater systems)	Environment Agency indicators
	Pesticides in fresh water	Measures nutrient enrichment and possible eutrophication (a significant pressure on freshwater systems)	Environment Agency indicators
	Abstraction from fresh waters	May indicate where abstractions limit water for use in natural environment	Environment Agency indicators
	Fragmentation of natural and semi-natural areas	A resilient natural environment should be well connected and have large networks which allow species to move in response to climate change	SEBI

Characteristic		Indicator	How it measures characteristic	Source
		Fragmentation of river systems	A resilient natural environment should be well connected and have large networks which allow species to move in response to climate change	SEBI
Flexible management		Progress in assessing and addressing the risks and opportunities of a changing climate	Planning is required to deliver a resilient natural environment – should focus on adaptive management	Local government performance indicator NI188
Ecosystem services	Supporting	Soil quality	Soil performs a vital provisioning service and a resilient natural environment should have high quality soil resources	Sustainable Farming and Food Strategy
	Provisioning	Livestock genetic diversity	A resilient natural environment requires a high level of genetic diversity	SEBI
	Cultural	Public awareness	Measures peoples knowledge of the natural environment and how to access it	SEBI
		Access to the countryside	Measures how many people access the countryside	Sustainable Farming and Food Strategy
		Countryside visit expenditure	Can be used to indicate how and where people access the environment and how they value it	Sustainable Farming and Food Strategy

A.2 Existing measurements

Table A.2 – Potential indicators from existing measurements

Characteristic	Measurement	Organisation responsible
Diversity	Remote sensing to measure land use, land use intensity and networks	
	Statutory site condition	Natural England
	Inland habitat creation	Environment Agency
	Species composition	
	Drought resilient forestry	Forestry Commission
Anthropogenic pressures within carrying capacity	Areas of healthy peat bogs	Natural England
	Area of functional floodplain	Environment Agency
	Surface flooding frequency	Environment Agency
	Algal blooms	Environment Agency
	Number of uncontrolled fires	Department for Communities and Local Government
	Number of 'no take zones' and Marine Protection Areas	Marine Management Organisation
	Water Framework Directive (WFD) monitoring – water quality	Environment Agency
	Soil moisture deficit	Met Office
	Outbreaks of disease or pests	
Flexible management	Management plans (Area of Outstanding Natural Beauty (AONB), National Parks) which consider adaptation	Various
	Environmental Stewardship agreements which consider adaptation	Natural England
	Flexible management e.g. managed realignment, boundary readjustments (in hectares, proportion affected by sea level rise)	Environment Agency Natural England
Ecosystem services	Area of matrix managed and enhanced within and between key econets (England Habitat Network)	Natural England
	Access to Natural Green Space (ANGS) measurements	Natural England

Appendix B

B.1 Literature review pro formas

Name and date	Local Government Performance indicators	
Publisher	Defra	
Link	http://www.defra.gov.uk/environment/localgovindicators/ni188.htm	
Description	NI188 is designed to measure the progress in preparedness of local authorities in assessing and addressing the risks and opportunities of a changing climate (Defra 2008). The indicator recognises that adapting to climate change is a continuous process; therefore Defra is looking for evidence that the local authority has put in place a mechanism for identifying and managing climate risks and opportunities in their decisions (Defra 2008). NI 197, Improved Local Biodiversity: proportion of Local Sites where active conservation management is being achieved. Evidence of positive (rather than active) conservation management is being or has been undertaken is required and will be used as a proxy for positive biodiversity outcome. The indicator will assess the proportion (%) of the total number of Local Sites under positive conservation management. Good performance, taking into account the variation in number of local sites in each Local Authority area, will be indicated by a year on year increase. NI194, Air quality: % reduction in NOx and primary PM10 emissions through local authority's estate and operations. The indicator is included in the final set of indicators on environmental sustainability.	
Type of indicator	NI 188: Process NI 194: Outcome NI 197: Outcome	
Relevance to Natural England	NI 188 is a good example of a process indicator. This could be a model for Natural England to follow but only if they have an agreed process of adaptation planning (could be the Character Area climate change project). The risk with adopting an indicator like this is that it measures the adaptation response rather than the effectiveness of the response. However, as one of a suite of indicators this could be very useful. The objective an adaptation process indicator measures is more likely to be policy based i.e. to have a policy or plan in place rather than focussing on delivery. The usefulness of this kind of indicator depends on the targets for adaptation held by Natural England.	
Measures characteristics?	High biodiversity value	NI 197
	Few pressures	NI 194
	Flexible management	NI188 could be adapted for Natural England to use as a process indicator, measuring progress in adaptation planning across its remit e.g. number of management plans which take climate change into account.
	Accessible to people	
	Strong ecosystem function	

Name and date	Streamlining European 2010 Biodiversity Indicators (SEBI)	
Publisher	European Environment Agency 2007	
Link	http://biodiversity-chm.eea.europa.eu/information/indicator/F1090245995	
Description	A Pan European initiative, SEBI2010 aims to develop a European set of biodiversity indicators to assess and inform progress towards the target of halting biodiversity loss by 2010. A first set of 26 indicators has been compiled. The indicators are grouped into 7 focal areas: • Status and trends of the components of biological diversity • Threats to biodiversity • Ecosystem integrity and ecosystem goods and services • Sustainable use • Status of access and benefits sharing • Status of resource transfers and use • Public opinion	
Type of indicator	Outcome indicators	
Relevance to Natural England	Although not directly climate adaptation related, these indicators may be relevant to the biodiversity function of Natural England. However many of them are focused on measuring impacts on biodiversity. There is one impact-related indicator: occurrence of temperature-sensitive species. Some of the indicators could be used to measure progress towards the Hopkins *et al*. (2007) principles for conservation of biodiversity in a changing climate. Few indicators measure flexible management and accessibility of the environment.	
Measures characteristics?	Diverse natural environment	Abundance and distribution of selected species Red List Index for European species Species of European interest Habitats of European interest Nationally designated protected areas Sites designated under the EU Habitats and Birds Directives Ecosystem coverage
	Anthropogenic pressures	Critical load exceedence for nitrogen Invasive alien species in Europe Occurrence of temperature-sensitive species Nutrients in transitional, coastal and marine waters Freshwater quality Agriculture: nitrogen balance Ecological Footprint of European countries
	Flexible management	

Name and date	Streamlining European 2010 Biodiversity Indicators (SEBI)	
	Ecosystem services	Public awareness Livestock genetic diversity Fragmentation of natural and semi-natural areas Fragmentation of river systems

Name and date	EEA Core Indicators	
Publisher	European Environment Agency 2004; European Environment Agency 2008	
Link	http://themes.eea.europa.eu/IMS/CSI	
Description	The EEA has a core set of 40 indicators representing 10 different categories. The 'climate change' category includes one impact-related indicator (Global/European temperature) and one mitigation related indicator (Greenhouse gas concentration) but no adaptation indicators. The 2008 indicator-based assessment summarises the relevance, past trends and future projections for 40 indicators. The indicators cover the impacts of climate change on atmosphere and climate, the cryosphere, marine systems, terrestrial systems and biodiversity, agriculture and forestry, soil, water quantity (including floods and droughts), water quality and fresh water ecology, and human health (EEA 2008).	
Type of indicator	Mostly outcome indicators CSI 015 Progress in management of contaminated sites, is a process indicator	
Relevance to Natural England	No adaptation indicators. Many potentially useful indicators of other pressures acting on ecosystems. The 2008 indicator-based assessment largely focuses on describing trends and impacts of climate change through reporting changes in its indicators. It measures impacts not adaptation. The report recognises that many of the research and assessment activities to date have focused on the climatological, physical and biological aspects of climate change impacts and that a better understanding of the socio-economic and institutional aspects of vulnerability and adaptation, including costs and benefits, is urgently needed. Very few studies have assessed the effectiveness of adaptation measures over a variety of time scales. Few indicators measuring flexible management and accessibility of the environment.	
Measures characteristics?	Diverse natural environment	CSI 008 – Designated areas CSI 009 – Species diversity CSI 007 – Threatened and protected species
	Anthropogenic pressures	CSI 005 – Exposure of ecosystems to acidification, eutrophication and ozone

Name and date	EEA Core Indicators	
		CSI 012 – Global and European temperature CSI 014 – Land take CSI 015 – Progress in management of contaminated sites CSI 020 – Nutrients in freshwater CSI 019 –Oxygen consuming substances in rivers CSI 024 – Urban waste water treatment CSI 018 – Use of freshwater resources
	Flexible management	
	Ecosystem services	CSI 025 – Gross nutrient balance

Name and date	UK Sustainable Development indicators	
Publisher	UK Government	
Link	http://www.defra.gov.uk/sustainable/government/progress/national/index.htm	
Description	To support the UK Government Sustainable Development Strategy there is a suite of 68 national sustainable development indicators. All the climate change indicators are focused on mitigation. Other indicators cover natural resources including aspects of Natural England's interests e.g. bird populations, biodiversity conservation.	
Type of indicator	Outcome	
Relevance to Natural England	The climate change indicators are not relevant to this project (mitigation not adaptation). Whilst the natural resources indicators are not designed to measure climate change impacts or adaptation they are connected – climate change will impact on bird populations, land use, environmental stewardship etc. It is possible that some of these could be used for Natural England's purposes although they are unlikely to cover adaptation. Few indicators measuring flexible management and accessibility of the environment.	
Measures characteristics?	Diverse natural environment	Area covered by agriculture, woodland, water or river, urban. Bird population indices (a) farmland birds and (b) woodland birds and (c) seabirds. Priority species status. Priority habitat status. Species and habitat status.
	Anthropogenic pressures	Total abstractions from non-tidal surface and ground water, leakage losses and GDP. Fertiliser input, farmland bird population, ammonia and methane emissions and output.

Name and date	UK Sustainable Development indicators	
		Land covered by 'higher level' environmental schemes, 1992 to 2007. NH_3, NO_x, PM_{10} and SO_2 emissions and GDP. Rivers of good biological quality, 1990 to 2006. Rivers of good chemical quality
	Flexible management	
	Ecosystem services	Resource availability status at low flows for units of surface water and / or surface water combined with groundwater, in Catchment Abstraction Management Strategy Areas. Land covered by 'higher level' environmental schemes, 1992 to 2007

Name and date	5 year measures of success for each target in the Natural England Strategic Direction Statement
Publisher	Natural England 2006
Link	http://naturalengland.etraderstores.com/NaturalEnglandShop/Product.aspx?ProductID=7b86c3d7-6b47-4dfc-ae6b-436c4268c3d3
Description	5 year measures of success: Outcome 1 • Net gain in securing and enhancing landscape character in all parts of the country and in each character area. • Major proportion of development, including urban regeneration and development, to make a significant contribution to reinforcing landscape character. • NPs and AONBs demonstrating an increasing level of exemplary management of our finest landscapes: including local character, cultural heritage, tranquillity, biodiversity in favourable condition, exemplary access management, resilience in adapting to climate change. • Ecosystems are healthier, dynamic and delivering increased resilience and capacity to adapt to change. • SSSIs are assessed for their resilience and ability to support healthy dynamic ecosystems able to adapt to change. • Widespread examples of landscape scale conservation, enhancement and management of the natural environment that can be replicated. • 2010 England Biodiversity Strategy targets met • Marine ecosystems and habitats have increased resilience and are more capable of adaptation. • A network of Marine Protected Areas identified that contribute to increasing the health and resilience of marine ecosystems.

Name and date	5 year measures of success for each target in the Natural England Strategic Direction Statement
	Outcome 2 • Increased percentage of target sectors of the population understanding and appreciating how the natural environment contributes to quality of life. • Increased prescription of walking outdoors as a part of a healthy lifestyle. • Increased percentage of people actively engaged to protect and enhance the natural environment. • An increased proportion of the population with high quality greenspace a short walk from their home. • An increased proportion of population using the natural environment more often. Outcome 3 • Land use is increasingly environmentally sustainable. • Spatial plans in each region provide a clear blueprint for land use that will actively conserve and enhance the natural environment. • Proportion of land managed in an environmentally sustainable way. • Proportion of spatial land management targets delivered, and quantification of the public benefits provided. • An increased proportion of our seas is used and managed sustainably. Outcome 4 • A spatial vision for the future (2050) natural environment in England which fully integrates the conservation and enhancement of landscapes, wildlife and benefits to people. • A (2050) Land Use Strategy for England that secures our environmental future and influences plans and funding at all levels of government. • New approaches to conserving and enhancing the natural environment generated through highlighting and understanding the future challenges we face. • Securing the adoption and recognition of the need for targets and funding for the natural environment at UK Government and European levels. • The CAP Healthcheck delivers maximum benefits for the natural environment • A shared vision for adaptation of our landscapes in response to climate change. • A legislative framework at both the UK and EU level that helps to secure our environmental future. • The major risks to the natural environment are understood and addressed by public bodies. • Increased proportion of habitats and ecosystems in ‘resilient condition’.

Name and date	5 year measures of success for each target in the Natural England Strategic Direction Statement	
	• Increased numbers of land managers actively managing more land for climate change adaptation and mitigation.	
Type of indicator	Outcome	
Relevance to Natural England	The Strategic Direction has clear objectives and targets but does it have associated indicators? The 5 year measures of success are largely qualitative. Most of the targets set in the Strategic Direction have definable end points so can be measured relatively easily. This is not the case for adaptation due to uncertainty over what the future will be like. The climate change adaptation objective suggests that Natural England are currently more focussed on enhancing adaptive capacity rather than delivering adaptation – implying doing more of what Natural England does already because it delivers adaptive capacity (as well as fulfilling other objectives).	
Measures characteristics?	Diverse natural environment	
	Anthropogenic pressures	
	Flexible management	
	Ecosystem services	

Name and date	PSA indicators
Publisher	Defra
Link	
Description	Defra is leading on one cross-government PSA “secure a healthy natural environment for everyone’s well being, health and prosperity, now and in the future” Progress towards delivering PSA28 will be measured against the following indicators: • Water quality as measured by parameters assessed by Environment Agency river water quality monitoring programmes • Biodiversity as indicated by changes in wild breeding bird populations in England, as a proxy for the health of wider biodiversity • Air quality – meeting the Air Quality Strategy objectives for eight air pollutants as illustrated by trends in measurements of two of the more important pollutants which affect public health: particles and nitrogen dioxide. • Marine health – clean, healthy, safe, productive and biologically diverse oceans and seas as indicated by proxy measurements of fish stocks, sea pollution and plankton status

Name and date	PSA indicators	
	• Land management – the contribution of agricultural land management to the natural environment as measured by the positive and negative impacts of farming PSA target 3 is relevant to Natural England: • Reversing the long-term decline in the number of farmland birds by 2020, as measured annually against underlying trends; • Bringing into favourable condition by 2010 95 per cent of all nationally important wildlife sites	
Type of indicator	Outcome	
Relevance to Natural England	Not explicitly adaptation related; these targets/indicators have a climate change dimension and could be used by Natural England. They could be seen as measuring adaptive capacity following the rationale that if sites are in favourable condition, they are more likely to be able to adapt to climate change. Few indicators measuring flexible management and accessibility of the environment.	
Measures characteristics?	Diverse natural environment	Reversing the long-term decline in the number of farmland birds Bringing into favourable condition by 2010 95 per cent of all nationally important wildlife sites
	Anthropogenic pressures	Positive and negative impacts of farming
	Flexible management	
	Ecosystem services	Water quality Air Quality Strategy objectives for eight air pollutants

Name and date	Environment Agency indicators	
Publisher	Environment Agency	
Link	http://www.environment-agency.gov.uk/research/library/data/34225.aspx	
Description	Range of indicators measuring Environment Agency progress under 9 themes: air, business and industry, climate, land, people and lifestyle, pollution, resources and waste, water and wildlife.	
Type of indicator	Outcome	
Relevance to Natural England	No indicators explicitly measuring adaptation but many that could be used to measure characteristics of a resilient natural environment (see below). Particularly useful for measuring pressures other than climate change on the natural environment. Few indicators measuring flexible management and accessibility of the environment.	
Measures characteristics?	Diverse natural environment	Wild bird populations Otter occurrence

Name and date	Environment Agency indicators	
	Anthropogenic pressures	Dangerous substances in water Pesticide use in agriculture and horticulture Soil loss to development Nutrients in rivers Pesticides in fresh water Air pollution
	Flexible management	
	Ecosystem services	Abstraction from fresh waters

Name and date	Sustainable Farming and Food Strategy Indicators	
Publisher	Defra	
Link	https://statistics.defra.gov.uk/esg/indicators/default.htm	
Description	A set of headline and core indicators has been developed as part of the process of monitoring and evaluating the progress of the Sustainable Farming and Food Strategy. Indicators cover the three pillars of sustainable development: environment, economy and social.	
Type of indicator	Outcome	
Relevance to Natural England	The indicators do not measure adaptation directly (although a new indictor looking at farming response to climate change is in development). However, many of the indicators are relevant to the natural environment and some measure the degree of resilience (see below). The indicators cover the full range of characteristics (although are farming focused).	
Measures characteristics?	Diverse natural environment	Species and biodiversity Habitats
	Anthropogenic pressures	Farming response to climate change Fertiliser use Pesticide use Water use for irrigation Invasive species
	Flexible management	
	Ecosystem services	Landscape value Access to the countryside Countryside visit expenditure River water quality Air quality Soil quality Genetic diversity

Name and date	Standards for accessible natural greenspace	
Publisher	Natural England	
Link	http://www.naturalengland.org.uk/ourwork/enjoying/places/greenspace/greenspacestandards.aspx	
Description	Natural England's Accessible Natural Greenspace Standard (ANGSt) provides a set of benchmarks for ensuring access to places near to where people live. They are a set of standards rather than indicators although progress towards them should be readily measurable as they are quantitative. These standards recommend that people living in towns and cities should have: • An accessible natural greenspace of at least 2 hectares in size, no more than 300 metres (5 minutes walk) from home • At least one accessible 20 hectare site within two kilometres of home • One accessible 100 hectare site within five kilometres of home • One accessible 500 hectare site within ten kilometres of home • Statutory Local Nature Reserves at a minimum level of one hectare per thousand population	
Type of indicator	Outcome	
Relevance to Natural England	May provide a good indicator of accessibility – something not covered well by other existing indicator sets.	
Measures characteristics?	Diverse natural environment	
	Anthropogenic pressures	
	Flexible management	
	Ecosystem services	An accessible natural greenspace of at least 2 hectares in size, no more than 300 metres (5 minutes walk) from home At least one accessible 20 hectare site within two kilometres of home One accessible 100 hectare site within five kilometres of home One accessible 500 hectare site within ten kilometres of home Statutory Local Nature Reserves at a minimum level of one hectare per thousand population